PREPARED FOR
**SANTA CLARA VALLEY
WATER DISTRICT**

Feasibility Study of Invasive Mussel Control Measures for Imported Water Facilities

MUSSEL CONTROL MEASURES FOR IMPORTED WATER INTAKE PROJECT

AGREEMENT # A3369A, PROJECT NO. 91452011

FINAL REPORT
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Executive Summary

The January 2007 discovery of quagga mussels in Lake Mead and subsequent spread throughout the lower Colorado River system, along with the January 2008 discovery of zebra mussels in the San Justo Reservoir in San Benito County, California, have created significant concern among owners and operators of water supply systems throughout the West. These non-native, invasive mussels are an environmental and economic nuisance, with the potential to harm ecosystems, affect water system reliability, damage equipment and infrastructure, and require significant investment to control.

It is possible that zebra or quagga mussels (dreissenid mussels) will establish a presence in the Santa Clara Valley Water District's (District) imported source water. For the District, infestation of invasive freshwater mussels in source water could result in reduced flows through intake and piping systems, increased energy use to pump water through clogged lines, damage to or impairment of water conveyance equipment, and taste and odor problems for delivered water if these negative impacts are not mitigated.

Project Objectives and Feasibility Study

The District wishes to protect its raw water systems that receive imported source water. Protection strategies should maintain District raw water operations and protect (or minimize impact to) District water treatment facilities.

This report serves as a feasibility study for alternatives to provide this protection. The feasibility study assists the District in achieving the project objectives by:

- Identifying and evaluating a comprehensive list of control methods for their ability to meet the District's protection objectives.
- Narrowing the list of control methods through a fatal flaw analysis and proposing protection strategy alternatives to be considered further.
- Developing basic design criteria and order-of-magnitude cost estimates for each protection strategy alternative.
- Ranking the alternatives through a weighted scoring process and recommending to the District the best alternative to be carried forward for conceptual design.

Protection/Mitigation Strategies and Alternatives

Strategies for protecting District equipment and resources from invasive mussels, or mitigating the impacts caused by mussels, have been grouped into three categories:

- Long-Term, Full-Barrier Protection Strategy Alternatives
- Short-Term, Partial-System Protection Strategy Alternatives
- Reactive Mitigation Alternatives

Long-Term, Full-Barrier Protection Strategy Alternatives (Full-Barrier Alternatives) involve a combination of mechanical filtration with chemical addition or ultraviolet (UV) irradiation for a multi-barrier approach. The mechanical filtration component is for control of adult and juvenile mussels, and the chemical addition or UV irradiation is intended to kill or damage mussel larvae to prevent establishment of mussel populations downstream and outside of the influence of the protection strategy. Full-Barrier Alternatives for the raw water system receiving South Bay Aqueduct (SBA) water (SBA System) are listed in Table ES-1. Full-Barrier Alternatives for the raw water system receiving San Luis Reservoir (SLR) water (SLR System) are listed in Table ES-2.

The Full-Barrier Alternatives would be implemented in an attempt to prevent any viable mussels from passing beyond a designated control location (e.g., Santa Clara Flow Meter Vault or Pacheco Pump Plant) within the raw water system. Meeting this objective would be protective of the downstream raw water system and receiving surface waters. It is important to note that 100 percent protection of the downstream system and receiving waters has never been attempted by a large water utility. The closest analogues are ballast water protection systems currently being tested. Mussel control methods have traditionally been implemented by utilities in response to infestations of mussels in their source water or system and have been designed to minimize the growth of mussels and/or mitigate the effects of mussels once they enter their system.

Full-Barrier Alternatives are very expensive and will require significant lead time to implement (estimated at 3 to 6 years). Consequently, Short-Term, Partial-System Protection Strategy Alternatives (Partial-Protection Alternatives) that could be implemented in less than 3 years are considered in this document. These alternatives involve pH adjustment or addition of chlorine or potassium to prevent settlement of mussels in protected segments of the system, and some elements of the Partial-Protection Alternatives may be compatible with the Full-Barrier Alternatives. Partial-Protection Alternatives for the SBA System are listed in Table ES-3. Partial-Protection Alternatives for the SLR System are listed in Table ES-4.

Because the Partial-Protection Alternatives do not involve filtration, they are less protective than the Full-Barrier Alternatives, as translocating juveniles and adults would likely survive the chemical treatments and could reach areas that are not protected. Some of the Partial-Protection Alternatives may also have greater impacts to water quality or the environment than the Full-Barrier Alternatives. Despite these drawbacks, they represent an improvement over the existing system in terms of protection from invasive mussels and minimization of impacts.

Table ES-1. Full-Barrier Alternatives for the South Bay Aqueduct System

Full-Barrier Alternatives	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria	Data gaps
Alternative 1: Filters and UV	Mechanical Filters, UV Irradiation (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; UV dose: 100 mJ/cm^2	Required UV dose
Alternative 2: Ferrate and Filters	Ferrate, Mechanical Filters (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ferrate dose: 1 mg/L	Ferrate is essentially a new treatment for the water industry. Need regulatory approval and pilot tests to confirm inactivation of veligers.
Alternative 3: Chlorine Dioxide and Filters	Chlorine Dioxide, Mechanical Filters (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Chlorine dioxide dose: <1.4 mg/L (assumed); Dechlorination at Piedmont Valve Yard and between the SBA Terminal Tank and recharge ponds with sodium bisulfite	Need pilot tests for effectiveness against veligers. Need bench tests to determine demand/decay on District water.
Alternative 4: Filters and Ozone	Mechanical Filters, Ozone (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ozone dose: <1 mg/L	

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
µm = micron
mg/L = milligrams per liter
mJ/cm^2 = millijoules per square centimeter
SBA = South Bay Aqueduct
UV = ultraviolet

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Table ES-2. Full-Barrier Alternatives for the San Luis Reservoir System

Full-Barrier Alternatives	Control Method for Protecting Vulnerable Equipment at the PPP	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Vulnerable Equipment at Coyote Pump Plant	Control Method for Protecting Reservoirs	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria	Data gaps
Alternative 1: Filters and UV	Supply pump cooling water and plant utility water from a point downstream of the filters and UV reactors	Mechanical Filters, UV Irradiation (located between pumps and regulating tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; UV dose: 100 mJ/cm^2	Required UV dose
Alternative 2: Ferrate and Filters	Ferrate	Mechanical Filters (located upstream of the PPP Regulating Tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ferrate dose: 1 mg/L	Ferrate is essentially a new treatment for the water industry. Need regulatory approval and pilot tests to confirm inactivation of veligers.
Alternative 3: Chlorine Dioxide and Filters	Chlorine Dioxide	Mechanical Filters (located upstream of the PPP Regulating Tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Chlorine dioxide dose: <1.4 mg/L (assumed); Dechlorination prior to the Hollister Biufurcation with sodium bisulfite	Need pilot tests for effectiveness against veligers. Need bench tests to determine demand/decay on District water.
Alternative 4: Filters and Ozone	Spot Treatments	Mechanical Filters (located between pumps and regulating tank), Ozone (located downstream of the PPP Regulating Tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ozone dose: <1 mg/L	

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
µm = micron
mg/L = milligrams per liter
mJ/cm2 = millijoules per square centimeter
PPP = Pacheco Pump Plant
UV = ultraviolet

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Table ES-3. Partial-Protection Alternatives for the South Bay Aqueduct System

Partial-Protection Alternatives	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria
Alternative 1: pH Adjustment	Protected in areas with pH greater than 9.3 (caustic soda added at Santa Clara Flow Meter Vault; sulfuric acid added at Piedmont Valve Yard and between SBA Terminal Tank and recharge ponds)	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	pH for protection against mussels: Greater than 9.3; Required caustic soda concentration: 12 mg/L; pH for discharge to surface water: Less than 8.5; Required sulfuric acid concentration: 11 mg/L
Alternative 2a: Chlorine	No protection against translocating adults downstream of dechlorination (chlorine added at Santa Clara Flow Meter Vault; sodium bisulfite added at Piedmont Valve Yard and between SBA Terminal Tank and recharge ponds)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dose: 2.5 mg/L to achieve 0.5 mg/L residual after 2 hours
Alternative 2b: Chlorine Dioxide	No protection against translocating adults downstream of dechlorination (chlorine added at Santa Clara Flow Meter Vault; sodium bisulfite added at Piedmont Valve Yard and between SBA Terminal Tank and recharge ponds)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dioxide dose: 1.4 mg/L (assumed)
Alternative 3a: Continuous Potassium Feed	Potassium chloride (added at Santa Clara Flow Meter Vault)	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Protected	Required KCl concentration: 20 mg/L
Alternative 3b: Periodic Potassium Feed	Potassium chloride added at Santa Clara Flow Meter Vault annually to kill settled mussels and minimize impacts	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Potassium chloride added annually to kill settled mussels and minimize impacts	Required KCl concentration: 20 mg/L Duration of addition period: 52 days
Alternative 4: Spot Treatments for Vulnerable Equipment	None	None	None	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	To be developed if selected

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
KCl = potassium chloride
mg/L = milligrams per liter
SBA = South Bay Aqueduct

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Table ES-4. Partial-Protection Alternatives for the San Luis Reservoir System

Partial-Protection Alternatives	Control Method for Protecting Vulnerable Equipment at the PPP	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Vulnerable Equipment at Coyote Pump Plant	Control Method for Protecting Calero Reservoir	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria
Alternative 1: pH Adjustment	pH Adjustment	Protected in areas with pH greater than 9.3; pH neutralization prior to the Hollister Bifurcation	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	pH for protection against mussels: Greater than 9.3; Required caustic soda concentration: 12 mg/L; pH for discharge to surface water: Less than 8.5; Required sulfuric acid concentration: 11 mg/L;
Alternative 2a: Chlorine	Chlorine	No protection against translocating adults downstream of dechlorination with sodium bisulfite (prior to the Hollister Biufurcation)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dose: 2.5 mg/L to achieve 0.5 mg/L residual after 2 hours;
Alternative 2b: Chlorine Dioxide	Chlorine Dioxide	No protection against translocating adults downstream of dechlorination with sodium bisulfite (prior to the Hollister Biufurcation)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dose: 1.4 mg/L (assumed)
Alternative 3a: Continuous Potassium Feed	Potassium chloride	Protected	Protected	Only protected if potassium concentrations remain high enough	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Protected	Required KCl concentration: 20 mg/L
Alternative 3b: Periodic Potassium Feed	Potassium chloride added annually to kill settled mussels and minimize impacts	Potassium chloride added annually to kill settled mussels and minimize impacts	Potassium chloride added annually to kill settled mussels and minimize impacts	None	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Potassium chloride added annually to kill settled mussels and minimize impacts	Required KCl concentration: 20 mg/L Duration of addition period: 52 days
Alternative 4: Spot Treatments for Vulnerable Equipment	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	None	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	None	None	None	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	Other design criteria to be developed if selected

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
KCl = potassium chloride
mg/L = milligrams per liter
PPP = Pacheco Pump Plant

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Reactive Mitigation Alternatives should be considered if mussels become established in the District system downstream of the designated control locations. They consist of periodic treatments to reduce the populations of settled adults within the raw water system or reservoirs. Reactive Mitigation Alternatives are listed in Table ES-5. Although these methods would not prevent mussels from entering the system and potentially settling in pipelines or local reservoirs, they may be part of a program to successfully maintain District raw water operations and to minimize impact to District water treatment facilities.

Table ES-5. Reactive Mitigation Alternatives

Mitigation Alternatives	Reactive Control Method for Settled Mussels	Basic Design Criteria
Alternative 1	pH Adjustment (Periodic treatment in conveyance system for 30 to 45 days)	pH for protection against mussels: Greater than 9.3 Required caustic soda concentration: 8 to 12 mg/L pH for discharge to surface water: Less than 8.5 Required sulfuric acid concentration: 9 to 11 mg/L
Alternative 2	Chlorine (Periodic treatment in conveyance system for 10 to 20 days)	0.5 mg/L chlorine residual at all targeted locations
Alternative 3	Potassium Chloride (Periodic treatment for 52 days)	Required concentration: 20 mg/L
Alternative 4	Bacteria-Based Molluscicide	Determine dose when more product information is available.

Key:
mg/L = milligrams per liter

Evaluation of Alternatives

The Full-Barrier and Partial-Protection alternatives were evaluated separately for the SBA and SLR systems using 10 (and in one case, 11) decision-making criteria. Each alternative was assigned a score between 0 and 10 for each criterion. Each decision-making criterion was assigned a weight, and the weighted scores were summed to provide a total score for each alternative. The alternative receiving the highest score was ranked the highest and is the recommended alternative for that raw water system.

Of the Full-Barrier Alternatives, chlorine dioxide and ferrate ranked higher than UV and ozone primarily because the associated costs were lower. Chlorine dioxide and ferrate also scored higher than UV and slightly higher than ozone in terms of protection from the impacts of invasive mussels.

Of the Partial-Protection Alternatives, Periodic Potassium Feed ranked the highest because it offered the second highest level of protection (after Continuous Potassium Feed) and the second lowest costs (after Spot Treatments for Vulnerable Equipment).

Recommended Protection Strategies

Full-Barrier Alternative 3, Mechanical Filters and Chlorine Dioxide, is the recommended Full-Barrier Alternative for both the SBA and SLR systems. Alternative 2, Mechanical Filters and Ferrate, was ranked second highest and should be considered if chlorine dioxide proves unable to meet the District's objectives. However, there are many data gaps associated with each of these alternatives and testing is needed to answer questions related to their implementation. The District should meet with the California Department of Public Health as soon as possible to present the results of this evaluation and communicate the District's plan for implementation.

Partial-Protection Alternative 3b, Periodic Potassium Feed, is the recommended Partial-Protection Alternative for both the SBA and SLR systems. Discussions should be held with the California Department of Public Health, California Department of Fish and Game, and the Regional Water Quality Control Board to determine the viability of implementing this alternative from a regulatory standpoint.

The intake trash racks on the San Luis Reservoir intakes need to be protected from settlement by dreissenid mussels and, because they are upstream of the designated control points, they will not be protected by the Full-Barrier or Partial-Protection alternatives. It is recommended that new intake trash racks, with a biofouling-resistant coating and vertical bars instead of a bar grid, be installed. Protection of the trash racks could be maximized by having removable trash racks and spares. Having more than one set of removable trash racks per intake would allow for more efficient and safer cleaning at the surface.

The total project costs to build and operate the recommended alternatives are significant. However, the costs resulting from mussel infestation in the District's raw water system, reservoirs, creeks, and recharge ponds without an existing protection strategy could also be significant. Such costs could be incurred through short-term and long-term responses, operational interruptions, and replacement of equipment or facilities. It is recommended that the District develop an estimate of costs that would be incurred if mussels arrive in source water before a protection strategy is in place. This information would be valuable during the process of deciding whether or not to proceed with the recommended protection strategies.

Bench- and Pilot-scale Testing

The primary by-product of feeding chlorine dioxide is chlorite, which is regulated by the United States Environmental Protection Agency and the California Department of Public Health at 1 mg/L. To assess whether feeding chlorine dioxide for mussel control is feasible without exceeding the regulatory standard, bench-scale testing, using SBA and SLR water, will be necessary to determine the demand and decay for chlorine dioxide and the resulting chlorite formation. Pilot testing will also be necessary to determine the necessary dose and contact time for chlorine dioxide to kill 100 percent of mussel veligers. It is recommended that similar testing with ferrate and potassium be performed in parallel in case the necessary chlorine dioxide dose is prohibitively high.

San Justo Reservoir is the closest location for pilot-scale testing at a water body that contains dreissenid mussels (in this case, zebra mussels). There are plans to use potassium to eradicate mussels from the reservoir, but the eradication efforts are not yet scheduled and are not expected to occur until after the summer of 2011.

Taste tests, using finished water with a range of concentrations of potassium, are recommended to help the District define upper limits of acceptable potassium concentrations.

Design

Conceptual designs of systems for mechanical filtration and addition of chlorine dioxide and periodic potassium feed have been prepared for the SBA and SLR systems (MWH, 2011). Detailed designs should be developed once bench- and pilot-scale testing supports the protection strategies.

Implementation

Ideally, the selected Full-Barrier Alternative will be operational prior to dreissenid mussel infestation of the District's imported source water. However, it is anticipated that a Full-Barrier Alternative will not be operational for three years or longer. In order to minimize the negative consequences that could occur if the District's source water becomes infested with mussels before then, it is recommended that the District design and construct the selected Partial-Protection Alternative. Operation of the Partial-Protection Alternative is not recommended unless mussels become established in imported source water or the District's raw water system prior to implementation of the Full-Barrier Alternative.

If mussels are detected in the District's source water or system before a Full-Barrier or Partial-Protection alternative is operational, the District should consider all options for minimizing the spread of mussels through the raw water system and whether any of the control measures described in this report may be implemented as a temporary solution more quickly than the selected Partial-Protection Alternative. Spot treatments for vulnerable equipment should be considered until the selected protection alternative is operational. Implementation of one of the Reactive Mitigation Alternatives may be necessary if mussels become established downstream of the recommended control measures in the District's raw water system or local reservoirs.

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Appendices

Appendix A Mechanical Filters

Abbreviations and Acronyms

°C	degrees Celsius
°F	degrees Fahrenheit
µm	micron
AF	acre-feet
AF/year	acre-feet per year
alum	aluminum sulfate
cfs	cubic feet per second
cm	centimeters
DBP	Disinfection By-Product
District	Santa Clara Valley Water District
DWR	California Department of Water Resources
EPA	United States Environmental Protection Agency
Fe	iron
ft/s	feet per second
FTT	Ferrate Treatment Technologies, LLC
Full-Barrier Alternatives	Long-Term, Full-Barrier Protection Strategy Alternatives
gpm	gallons per minute
HOCl	hypochlorous acid
MBI	Marrone Bio Innovations, Inc.
mg/L	milligrams per liter
mgd	million gallons per day
mJ/cm^2	millijoules per square centimeter
mL	milliliter
mm	millimeter
msl	mean sea level
nm	nanometer
NSF	National Sanitation Foundation
O&M	operations and maintenance
OCl^-	hypochlorite ion
ppm	parts per million
PPP	Pacheco Pump Plant
psi	pounds per square inch
PWTP	Penitencia Water Treatment Plant

Reclamation	United States Department of the Interior, Bureau of Reclamation
SBA	South Bay Aqueduct
SBA System	SCVWD’s raw water system receiving SBA water
SCVWD	Santa Clara Valley Water District
SLR	San Luis Reservoir
SLR System	SCVWD’s raw water system receiving SLR water
STWTP	Santa Teresa Water Treatment Plant
THM	trihalomethanes
TSS	Total Suspended Solid
UV	ultraviolet
UVT	UV transmittance

1.0 Project Background and Objectives

The January 2007 discovery of quagga mussels in Lake Mead and subsequent spread throughout the lower Colorado River system, along with the January 2008 discovery of zebra mussels in the San Justo Reservoir in San Benito County, California, have created significant concern among owners and operators of water supply systems throughout the West. These non-native, invasive mussels are an environmental and economic nuisance, with the potential to harm ecosystems, affect water system reliability, damage equipment and infrastructure, and require significant investment to control.

It is possible that zebra or quagga mussels (dreissenid mussels) will establish a presence in the Santa Clara Valley Water District's (SCVWD or District) imported source water. For the District, infestation of invasive freshwater mussels in source water could result in reduced flows through intake and piping systems, increased energy use to pump water through clogged lines, damage to or impairment of water conveyance equipment, and taste and odor problems for delivered water if these negative impacts are not mitigated.

The District is already taking proactive measures to keep invasive mussels out of its reservoirs with boating inspections on four reservoirs and closure of boating on others except by special permit (i.e., rowing club, ski club, etc.). The District has conducted mussel vulnerability assessments of three pumping plants, local reservoirs, and water treatment plants. The District has also implemented regular mussel monitoring and has developed an invasive mussel response plan.

1.1 Dreissenid Impacts to Water Supply Systems

Dreissenid mussels are aggressive bio-foulers. There are two main types of fouling: acute and chronic. It is essential that any facility experiencing mussel fouling be prepared to deal with both types of fouling.

Chronic fouling occurs when juvenile dreissenid mussels attach themselves to external and internal structures. The juvenile mussels grow in place and reduce water flow and, in some cases, can even cut off the water flow.

Acute fouling occurs when a large build up of adult mussel shells, alive or dead, becomes detached from upstream locations and is carried by the water flow into piping systems. The large quantities of mussel shells quickly plug small diameter pipes, fixed strainers, filters and heat exchangers. Such events can occur at unexpected times and, if not anticipated, can have rapid and significant consequences.

1.2 Project Objectives and Feasibility Study

The District wishes to protect its raw water systems that receive imported source water. Protection strategies should maintain District raw water operations and protect (or minimize impact to) District water treatment facilities.

This report serves as a feasibility study for alternatives to provide this protection. The feasibility study assists the District in achieving the project objectives by:

- Identifying and evaluating a comprehensive list of control methods for their ability to meet the District's protection objectives.

- Narrowing the list of control methods through a fatal flaw analysis and proposing protection strategy alternatives to be considered further.

- Developing basic design criteria and order-of-magnitude cost estimates for each protection strategy alternative.

- Ranking the alternatives through a weighted scoring process and recommending to the District the best alternative to be carried forward for conceptual design.

2.0 SCVWD and Imported Water Facilities

2.1 Overview of SCVWD System and Water Supplies

SCVWD provides watershed stewardship, wholesale water supply, and flood protection for Santa Clara County, California, in the southern San Francisco Bay Area. The District encompasses all of the county’s 1,300 square miles and serves the area’s 15 cities and 1.7 million residents. The District's three water treatment plants can produce as much as 210,000,000 gallons of drinking water a day.

Approximately half the water used in the county originates in the Sierra Nevada and is delivered through the Sacramento-San Joaquin River Delta or the Hetch Hetchy Aqueduct system. Most of the remainder comes from local rainfall, much of which is captured in the water district’s 10 local reservoirs.

Forty percent of Santa Clara County’s water supply is conveyed through the Sacramento–San Joaquin River Delta. This water is supplied to the north side of the District via the South Bay Aqueduct (SBA), and to the south side of the District via San Luis Reservoir and the San Felipe System, as shown on Figures 2-1 and 2-2.

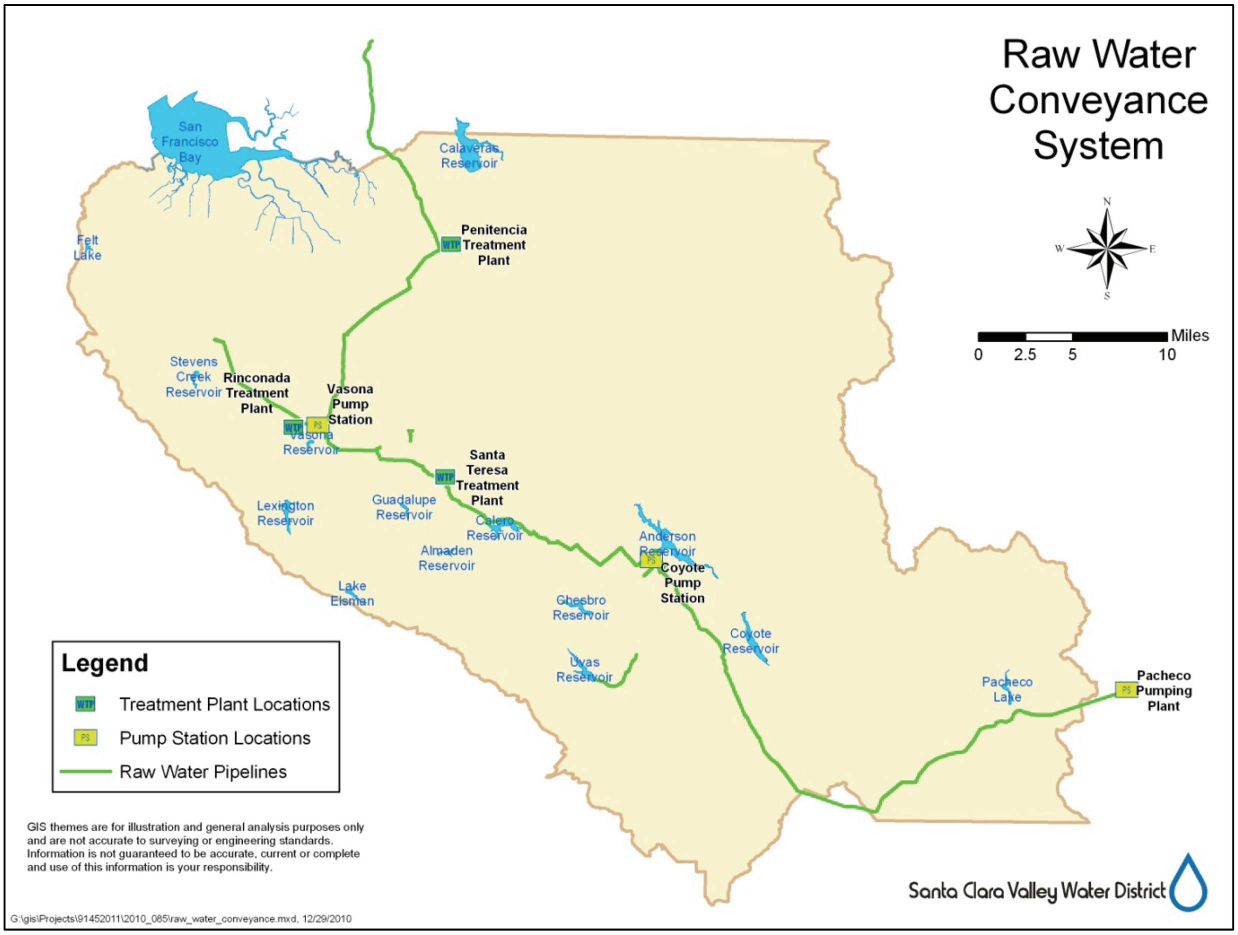
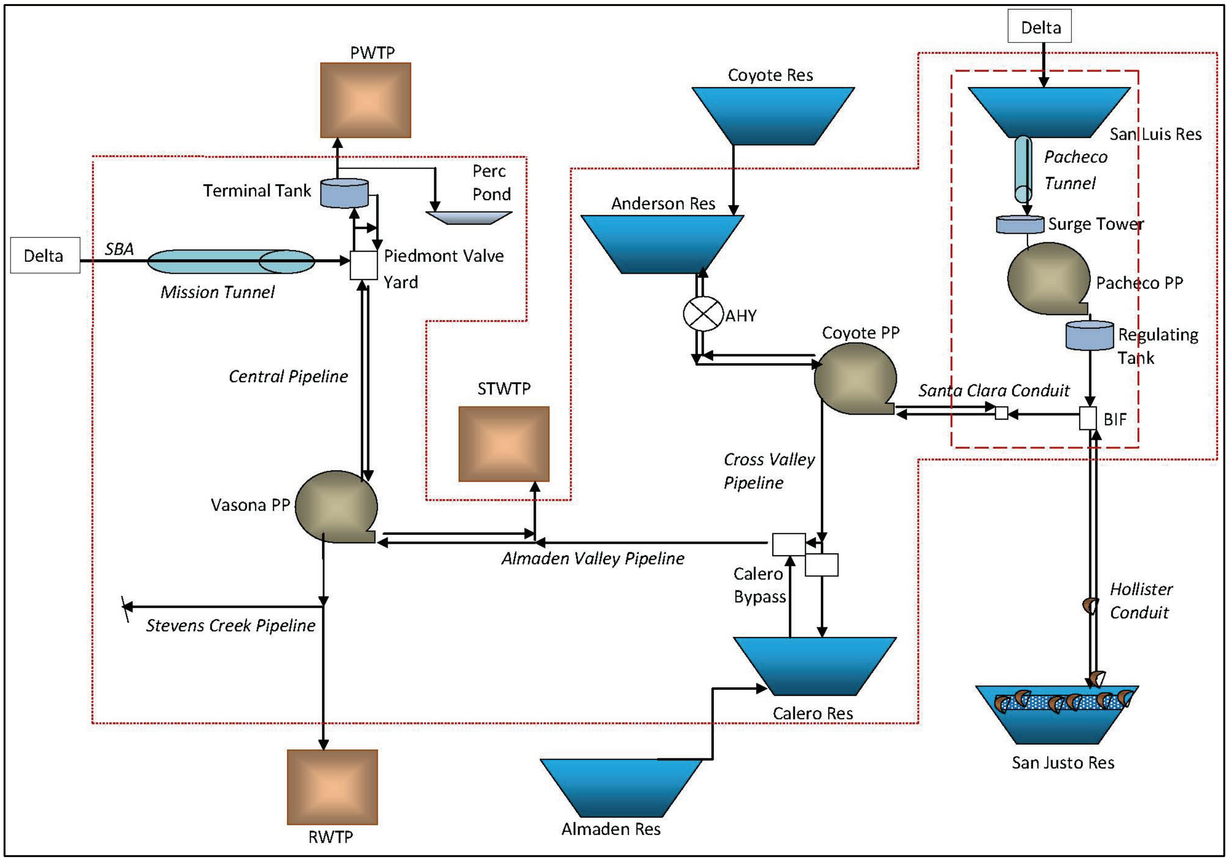

Raw Water Conveyance System
N
W
E
S
Miles
0
2.5
5
10
San Francisco Bay
Calaveras Reservoir
Felt Lake
Penitencia Treatment Plant
WTP
Stevens Creek Reservoir
Rinconada Treatment Plant
Vasona Pump Station
PS
Vasona Reservoir
Santa Teresa Treatment Plant
Lexington Reservoir
Guadalupe Reservoir
Calero Reservoir
Almaden Reservoir
Anderson Reservoir
Coyote Pump Station
Lake Elsman
Chesbro Reservoir
Coyote Reservoir
Uvas Reservoir
Pacheco Lake
Pacheco Pumping Plant
Legend
WTP Treatment Plant Locations
PS Pump Station Locations
Raw Water Pipelines
GIS themes are for illustration and general analysis purposes only and are not accurate to surveying or engineering standards. Information is not guaranteed to be accurate, current or complete and use of this information is your responsibility.
Santa Clara Valley Water District
G:\gis\Projects\91452011\2010_085\raw_water_conveyance.mxd, 12/29/2010

Figure 2-1. Raw Water Conveyance System Map



Source: L. Young, Santa Clara Valley Water District, December 21, 2010

Figure 2-2. Raw Water Operations System Flow Diagram

2.2 SBA Delivery to SCVWD

The SBA enters the District at the Mission Tunnel and travels approximately 5.6 miles before splitting east to the SBA Terminal Tank at Penitencia Water Treatment Plant (PWTP) and west to the Central Pipeline. Flow rates in this section of the SBA range from 0 to 185 cubic feet per second (cfs), as measured at the Santa Clara Flow Meter Vault. Typical flow rates are 50 cfs in the winter and 100 cfs in the summer. The minimum travel time for water in the SBA from the Santa Clara Flow Meter Vault to PWTP is 1.7 hours (personal communication with Mike Devore, SCVWD, October 20, 2010).

2.3 San Luis Reservoir Intakes and Facilities

San Luis Reservoir has a capacity of 2,015,600 acre-feet, with a water surface elevation of 545 feet above mean sea level (msl) when full. There are two SCVWD intakes in San Luis Reservoir, located at elevations 334 and 376 feet msl, as shown on Figure 2-3. The intakes have removable trash racks with fairly wide spacing of vertical bars and horizontal supports. Stainless steel screen mesh with less than 2-inch spacing has been bolted to the outside of the original steel bars to prevent large objects from entering.

The Pacheco Pump Plant (PPP) withdraws water from San Luis Reservoir. Water travels from the intakes to the PPP suction vault via the 9.5-foot diameter Pacheco Tunnel. From there, 12 identical vertical-shaft multistage pumps deliver water to a common discharge manifold. The discharge manifold delivers water to a regulating tank for subsequent delivery via gravity into the Pacheco Conduit, as shown in Figure 2-4. From the Pacheco Conduit, water can be delivered to San Benito County via the Hollister Conduit, or to the District via the Santa Clara Tunnel.

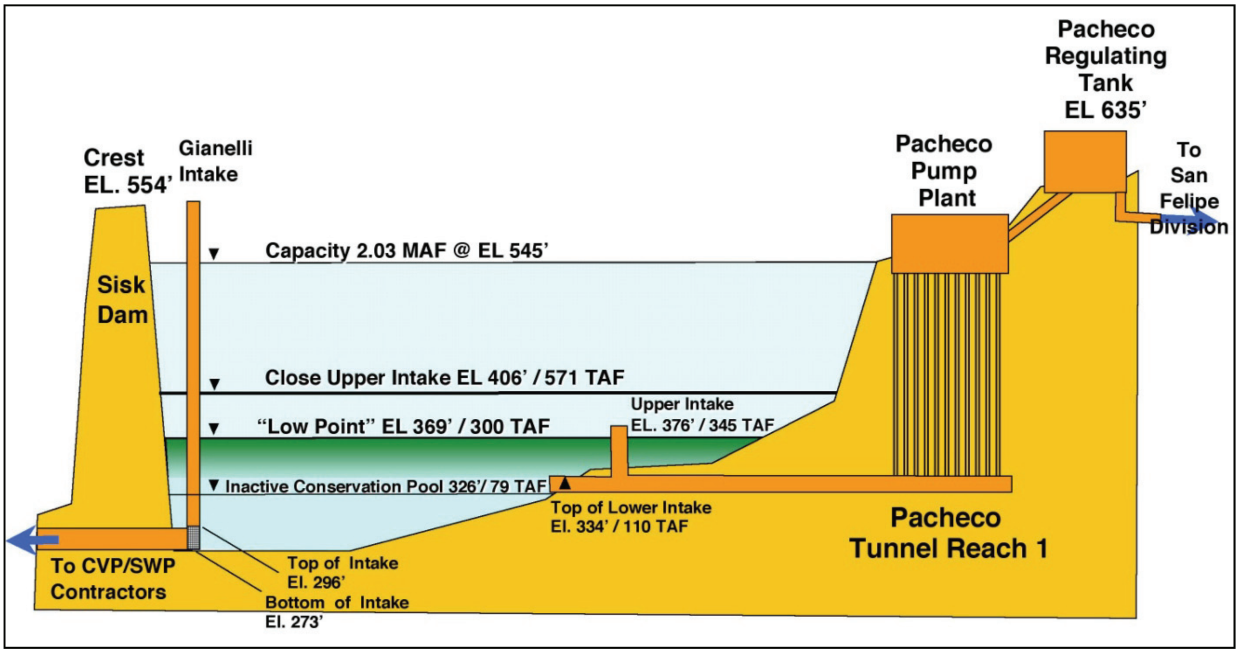

Pacheco Regulating Tank EL 635'
Crest EL. 554'
Gianelli Intake
Pacheco Pump Plant
To San Felipe Division
Capacity 2.03 MAF @ EL 545'
Sisk Dam
Close Upper Intake EL 406' / 571 TAF
Upper Intake EL. 376' / 345 TAF
"Low Point" EL 369' / 300 TAF
Inactive Conservation Pool 326'/ 79 TAF
Top of Lower Intake El. 334' / 110 TAF
Pacheco Tunnel Reach 1
To CVP/SWP Contractors
Top of Intake El. 296'
Bottom of Intake El. 273'

Figure 2-3. Schematic of San Luis Reservoir and Pacheco Pump Plant

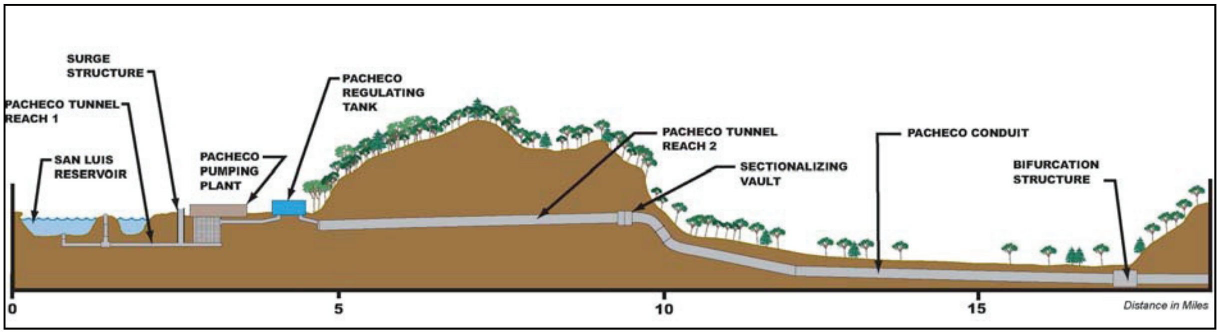


Figure 2-4. Profile from San Luis Reservoir to Bifurcation Structure

Flow rates at the PPP range from 0 to 480 cfs. Typical flow rates are 100 cfs in the winter and 350 cfs in the summer. The minimum travel time for water from the PPP to the Hollister Bifurcation is 3 hours (SCVWD, 2009) and the minimum travel time for water from the PPP to Santa Teresa Water Treatment Plant (STWTP) is 18.8 hours (personal communication with Mike Devore, SCVWD, October 20, 2010).

2.4 Vulnerabilities of Imported Water Facilities to Dreissenids

The September 2010 technical memorandum, *Vulnerability of Imported Water Facilities and Potential Impacts from Invasive Dreissenid Mussels* (RNT, 2010), found that imported source water facilities which receive water from the SBA and San Luis Reservoir have potential vulnerability to negative impacts from dreissenid mussels. Calcium, pH, temperature, and dissolved oxygen data for the SBA suggest the possibility of moderate infestations of dreissenid mussels in the future. Calcium, pH, temperature, and dissolved oxygen data for San Luis Reservoir suggest the possibility of moderate-to-high infestations of dreissenid mussels in the future.

Large diameter piping and tunnels are not at risk of plugging from mussels, but they are at risk of mussel settlement on the walls. Some increased hydraulic roughness is to be expected from mussel attachment, and the increased hydraulic friction will reduce the maximum flow that can be achieved in this largely gravity-based piping system. Provided the system flow capacity is oversized, some increased hydraulic roughness should be tolerable. Once source waters reach the water treatment plants, live mussels or dead shells will be removed.

Large valves are typically impacted only minimally by mussels. Smaller components, such as air release valves, blow off valves, instrument lines, and level gauges, could suffer from impaired performance and may require increased maintenance.

Should mussel accumulation occur, and be tolerable in the raw water system piping, settled mussels will eventually become a source of dead shell material that will be transported along the piping and deposited in areas of low flow velocities. The SBA Terminal Tank, PPP forebay vault, and PPP regulating tank are locations where low velocity water flow will allow transported mussel shells to settle out. Some increased cleaning of the areas of low flow would become necessary.

Raw water is used at pump plants, like the PPP, Vasona Pump, and Coyote Pump Plant, for pump cooling water, service water, and fire protection. Protection is needed for these systems if mussels become established in imported source water.

According to the technical memorandum, protection strategies for the District include:

1) periodic treatment for maintenance purposes, and

2) continuous treatment to prevent passage of veligers downstream of vulnerable equipment.

If periodic treatment for maintenance purposes is selected, it is possible that a once per year treatment could be practical, given the projected levels of infestation based on environmental data. This practice would allow one year of mussel growth within the system between treatments.

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3.0 Evaluation of Potential Control Methods

A comprehensive list of possible Dreissenid control methods is included in Table 3-1 and described in the following sections. The control methods and the supporting text are largely from *Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems* (Mackie and Claudi, 2010).

Table 3-1 also identifies each control method as proactive, reactive, or both. In this report, proactive strategies are defined as those which can prevent mussels from settling and surviving at any point downstream from the control method(s). Reactive strategies are those which can be applied periodically to control established mussel populations within the raw water distribution system or local reservoirs.

Control methods that are candidates for application as part of a protection strategy alternative are listed in Table 3-2. Each control method has been categorized to indicate whether it would be used proactively or reactively, and which mussel life stage it is intended to control. Basic design criteria, such as pore size and dosing information, are also listed.

3.1 Control Methods That Involve Oxidizing Chemicals

Oxidizing chemicals have been utilized as disinfectant agents in water supply systems for over one hundred years, and in most cases their effect on the environment is understood and well documented. Treatment with oxidizing chemicals (primarily chlorine) has been the most frequently used proactive chemical treatment to-date in the fight against mussel fouling. Chlorine-based chemicals, including gaseous chlorine, sodium hypochlorite, chloramines, and chlorine dioxide, have all been used successfully for control of zebra and quagga mussels. The particular form of chlorine-based chemical used has proven to be largely a matter of utility preference, which depends on several factors, including perception of safety, cost, convenience of use, location, and experience.

3.1.1 Chlorine

One of the most effective and popular methods of biofouling control is chlorination, where chlorine is added as dissolved diatomic chlorine gas (hypochlorous acid), liquid sodium hypochlorite, or solid calcium hypochlorite. Chlorine has been used for over one hundred years in the treatment of potable water. It is a well known and studied chemical, with well documented use and by-products.

Utilities typically prefer sodium hypochlorite to gas chlorine systems for safety reasons, even though it is more complex to use, is generally more expensive, and causes more housekeeping problems.

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Table 3-1. Summary of Control Methods

Protection Strategy	Strategy Type (Proactive or Reactive)	Advantages	Disadvantages	Candidate Control Method for SCVWD Application
Chlorine	Proactive or Reactive (depending on the application)	Lengthy history of use in controlling various lifestages of mussels. Pre-chlorination is already used at District water treatment plants and the District staff are familiar with its application.	Forms DBPs such as trihalomethanes and haloacetic acids. Requires removal prior to reservoir storage.	**Yes**
Chloramines	Proactive	Less DBP formation than chlorine. Longer lasting residual than chlorine.	Less potent disinfectant than chlorine. Requires removal of chlorine and ammonia prior to reservoir storage, due to toxicity to fish and potential for increased algae growth with increased ammonia concentrations.	No
Chlorine Dioxide	Proactive or Reactive (depending on the application)	Relatively common disinfectant chemical. Does not form trihalomethanes or haloacetic acids.	More-complicated process than chlorine and chloramines. High costs to generate chlorine dioxide. Degrades to chlorite and chlorate, which may require removal. Requires removal prior to reservoir storage.	**Yes**
Ozone	Proactive or Reactive (depending on the application)	Very strong disinfectant.	Short-lived residual. Potential pipeline corrosion. High costs. Potential to form bromate. Forms AOCs which may create biofilm.	**Yes**
Ferrate	Proactive	Very powerful oxidant and disinfectant. Environmentally friendly.	Not used extensively within water treatment industry.	**Yes**
Bromine	Proactive or Reactive (depending on the application)	Similar to chlorine.	Not used extensively within water treatment industry. Incompatible with ozone treatment.	No
Hydrogen Peroxide	Proactive	No DBPs.	More expensive than chlorine. More dangerous to store and handle. Doses for use with mussels are not well-defined.	No

Table 3-1. Summary of Control Methods (cont.)

Protection Strategy	Strategy Type (Proactive or Reactive)	Advantages	Disadvantages	Candidate Control Method for SCVWD Application
Potassium Permanganate	Proactive	Relatively-simple dry feed system.	Not acutely toxic to either veligers or adults. Adds manganese to water.	No
Proprietary Molluscicides	Reactive	Cause significant mortalities in adult dreissenid mussels.	Many of these products are toxic to a wide variety of species and not just mollusks. Requires detoxification with the addition of bentonite clay slurry.	No
Mexel	Proactive	Inhibits the formation of byssal threads of dreissenid mussels. Does not require detoxification on discharge.	Not used in drinking water systems.	No
Bacteria-Based Molluscicide	Reactive[1]	Molluscicide is a naturally-occurring bacterium found in soil.	Not currently approved for drinking water applications.	**Yes[2]**
BioBullets	Reactive	Targeted delivery of noxious substances to adult mussels.	No impact on veligers. Does not meet the objective of preventing veligers from reaching local reservoirs. Biobullets have a toxic core and all that is not ingested by mussels is released into the environment.	No
Ammonium Nitrate	Proactive	Shown to cause mortality in adults and veligers.	High ammonia concentrations require removal prior to reservoir storage. Expensive.	No
Copper Sulfate	Reactive	Already added to the SBA by DWR. Has been shown to cause mortality of veligers and is likely to control adult populations.	High cost. Possible impacts to reservoir fish.	No
Potassium Salts (including potash)	Typically Reactive, but potentially Proactive	Shown to cause mortality in adults and prevent settlement.	Causes mortality in native bivalves.	**Yes**
Sodium Metabisulfite	Reactive	Addition of sodium metabisulfite decreases oxygen concentrations, decreasing suitability of the environment for infestations.	High costs (enormous amounts of the compound would be required for treatment).	No

Table 3-1. Summary of Control Methods (cont.)

Protection Strategy	Strategy Type (Proactive or Reactive)	Advantages	Disadvantages	Candidate Control Method for SCVWD Application
Coagulation / Flocculation	Proactive	Can kill or remove veligers.	Impractical to protect the raw water system and would add coagulant sludge.	No
Salinity	Proactive	Acute toxicity has been observed in veligers at salinity levels of 8.5 parts per thousand.	Incompatible with a drinking water supply system.	No
pH Adjustment	Proactive or Reactive (depending on the application)	Relatively inexpensive, simple to operate, and free of any disinfection byproducts or other water quality concerns.	Many data gaps, including effectiveness as a control method and impacts to reservoirs and water treatment plants.	**Yes**
UV Irradiation	Proactive	No chemical addition. Provides disinfection without DBPs.	Provides no residual (dose must be delivered within reactor residence time).	**Yes**
Infiltration Gallery	Proactive	Completely effective at removing all lifestages.	High costs. High headloss.	No
Media Filtration	Proactive	Completely effective at removing all lifestages.	High cost.	No
Mechanical Filtration	Proactive	Removal of juvenile and adult lifestages without chemical addition.	Headloss, treatment and disposal of backwash water and solids, diversion of some water for backwashing. Inability to remove fertilized eggs and early larval stages.	**Yes**
Membrane Filtration	Proactive	Completely effective at removing all lifestages.	High cost.	No
Antifouling and Foul-Release Coatings	Proactive (only at the location where applied)	May protect infrastructure upstream of other control methods.	Costs and methods of application.	**Yes**
Speed of Flow	Proactive (only at the location where applied)	Prevents settlement.	Does not prevent invasive mussels from settling and surviving in other parts of the system where speed of flow is decreased.	No
Electric Currents	Proactive (only at the location where applied)	Prevents settlement.	Impractical for most applications at the voltages necessary, the required length of exposure, and the amount of power needed.	No

Table 3-1. Summary of Control Methods (cont.)

Protection Strategy	Strategy Type (Proactive or Reactive)	Advantages	Disadvantages	Candidate Control Method for SCVWD Application
Acoustics	Proactive or Reactive (depending on the application)	May kill mussels and/or prevent settlement.	Would only be practical to protect small areas of the District's raw water system, if at all.	No
Magnetic Fields	Proactive or Reactive (depending on the application)	No chemical addition.	Unproven, in terms of effectiveness.	No
Mechanical Cleaning	Reactive	Relatively inexpensive method of minimizing the impacts of settled mussels.	Does not prevent invasive mussels from entering or settling in the system. Only periodically results in removal of mussels from a limited area.	No
High and Low Pressure Water Cleaning	Reactive	Relatively inexpensive method of minimizing the impacts of settled mussels.	Does not prevent invasive mussels from entering or settling in the system. Only periodically results in removal of mussels from a limited area.	No
Thermal Shock	Reactive	Can kill colonies of mussels in a matter of hours.	Can only be applied periodically when the system to be protected is not in use.	**Yes**
Desiccation	Reactive	Can kill colonies of mussels if allowed to dry for periods of hours to weeks (depending on the temperature and humidity).	Can only be applied periodically and may have significant impacts to operations.	No
Oxygen Deprivation	Reactive	Can kill colonies of mussels if low oxygen concentrations are sustained for several weeks.	Can only be applied periodically and may have significant impacts to operations.	No

Notes:

[1] Bacteria-Based Molluscicides may be used as a proactive continuous treatment if veliger mortality is demonstrated with testing

[2] Bacteria-Based Molluscicides are not currently approved for drinking water applications, and there would be several water quality and permitting issues to address for implementation

Key:
AOC = assimilable organic compounds
DBP = disinfection byproduct
DWR = California Department of Water Resources
SCVWD = Santa Clara Valley Water District

Table 3-2. Candidate Control Methods

Control Method	Targeted Life Stage	Concentration (Assumed)	Required Contact Time (Assumed)	Data Gaps
Chlorine	Larvae or Settled Mussels	0.5 mg/L	120 minutes	Lowest possible dose to achieve objectives in the SBA or PPP systems
Chlorine Dioxide	Larvae	1 mg/L (?)	120 minutes (?)	Concentration and contact time for 100% kill of larvae in flowing conditions
Ozone	Larvae	1 mg/L	30 minutes (?)	Concentration and contact time for 100% kill of larvae in flowing conditions
Ferrate	Larvae	1 mg/L	Pilot testing needed	Concentration and contact time for 100% kill of larvae in flowing conditions
Bacteria-Based Molluscicide	Settled Mussels	Ongoing tests by manufacturer	Ongoing tests by manufacturer	Concentration, contact time, date of availability for use, and pricing
Potassium Salts	Settled Mussels	20 mg/L	52 days	Lowest possible dose to achieve objectives; possibility of regulatory approval
pH Adjustment	Settled Mussels	9.3 to 9.5	Continuous application to prevent survival	Effectiveness for preventing settlement
UV Irradiation	Larvae	100 mJ/cm^2		Complete dose understanding for 100% inactivation of larvae in flowthrough conditions.
Mechanical Filter, 120 – 150 µm Absolute Pore Size	Juveniles and Adults	N/A	N/A	Expected range of site-specific headloss; Performance under site-specific silt load
Antifouling and Foul-Release Coatings	Ready-to-Settle Mussels	N/A	N/A	Reclamation has been testing metal alloys and protective coatings for their effectiveness at resisting fouling; the results should be reviewed prior to selecting a coating.
Thermal Shock	Settled Mussels	One hour at 104°F or two days at 90°F		

Key:
°F = degrees Fahrenheit
mg/L = milligrams per liter
N/A = not applicable
PPP = Pacheco Pump Plant
SBA = South Bay Aqueduct
µm = micron

Various strategies exist for the use of chlorine against macrofouling. They range from a continuous addition of small volume of chlorine to eliminate any settlement in the system to once/year addition of higher chlorine concentration to eliminate settled adults. Some utilities have found that zebra and quagga mussel control locations can easily serve as a point of water treatment plant prechlorination. But in cases where the point of withdrawal is remote from the treatment plant, some utilities must add more chlorine prior to water treatment.

Chlorine may be used to kill adult, juvenile, and/or larval quagga or zebra mussels depending on the residual and duration of contact in the areas to be protected. Continuous treatment, at 0.5 milligrams per liter (mg/L) total residual chlorine, has been used successfully at several Ontario Hydro facilities (Claudi, 1992). This treatment prevented new settlement and caused 100 percent mortality in the adult mussels that previously settled in the system (Mackie and Claudi, 2010).

Destruction of mussels in the larval stages may be accomplished by maintaining a continuous low residual in the entire flow system or those areas that cannot be protected or periodically cleaned by other methods. Klerks (1993) observed 100 percent mortality in veligers exposed to 0.5 mg/L total residual chlorine for 2 hours in static systems. For this report, it is assumed that a dose of 2.5 mg/L is necessary to maintain a total residual chlorine concentration of 0.5 mg/L for two hours.

One of the major concerns in using chlorination in surface water supplies is that it combines with various naturally-occurring organic compounds to form disinfection by-products (DBPs), some of which are considered possible carcinogens. The October 2009 memorandum, “Disinfection at Pacheco Pump Plant for Mussel Control to San Luis Pipeline” (SCVWD, 2009), describes testing that was performed on May 21, 2009, using San Luis Reservoir water. The tests showed that a chlorine residual of 0.5 mg/L can be maintained for only two hours if chlorine is added at 2.5 mg/L. However, when this dose of chlorine was added to the particular sample tested, 72 µg/L total trihalomethanes (THM) were formed. THMs are regulated at 80 µg/L, based on a running annual average. Because the District’s three water treatment plants add chlorine to meet disinfection requirements of the Surface Water Treatment Rule, feeding chlorine for mussel control in the raw water transmission system would almost certainly result in a violation of the THM standard in water supplied to the District’s customers.

In addition to the health concerns related to DBPs, the Regional Water Quality Control Board, San Francisco Bay Region has set effluent limits for some DBPs (including bromoform, dibromochloromethane, and bromodichloromethane) in water discharged to surface water bodies for 250 or more days per year. These effluent limits would be exceeded if chlorine is added to raw water upstream of the local reservoirs.

Additionally, most regulatory agencies permit the use of chlorine in flow-through systems but have stringent limitations on the level of total residual chlorine in discharges to a surface water body. To meet these requirements, most facilities have to de-chlorinate the treated stream or else utilize a storage lagoon or a large volume of dilution water.

Because it is one of the most effective and popular methods of biofouling control, chlorine was selected as a Candidate Control Method. However, chlorine is only considered for short-term protection strategies, not long-term protection strategies (see Section 4), because of the concerns about the formation of DBPs.

Sodium hypochlorite could be injected upstream of the Santa Clara Flow Meter Vault to be part of a protection strategy for the SBA and injected upstream of the PPP (in the intake tunnel or at the surge tower) to be part of a protection strategy for water from San Luis Reservoir. Diffuser piping would be used to ensure adequate mixing. Further mixing would occur at any downstream pumps. Tests should be performed to determine if additional dechlorination will be required at downstream locations.

3.1.2 Chloramines

Chloramines are formed when free available chlorine (hypochlorous acid (HOCl) and hypochlorite ion (OCl^-)) reacts with compounds containing nitrogen such as ammonia and amino acids. Chloramines can be generated in bulk by co-injection of sodium hypochlorite and ammonia as either dissolved ammonia gas or ammonium hydroxide. Chloramine is a less potent disinfectant than HOCl and similar to that of the OCl^-. However, the chloramine residual lasts longer than the chlorine residual, and chloramines produce fewer regulated disinfection byproducts. Chloramine is commonly used as a disinfectant in drinking water where precursors in the source water would cause potential problems with THMs, or to get longer-lasting residuals in long residence-time systems.

Chloramines may be used to kill quagga or zebra mussels depending on the residual and duration of contact in the areas to be protected. Chloramines have been used effectively for mussel control at locations such as the Oshkosh, Wisconsin water treatment plant intake system and are being considered for a Lake Powell (Utah) pipeline.

Use of chloramines would require removal of ammonia prior to reservoir storage because ammonia, even at low concentrations, can be toxic to fish and additional ammonia in the terminal reservoirs would also increase nutrient levels and could lead to algae blooms. Because removal of ammonia is not considered to be practical, chloramines were not selected as a Candidate Control Method.

3.1.3 Chlorine Dioxide

Chlorine dioxide has been implemented as a disinfectant in the water treatment industry for over fifty years. It typically must be manufactured on-site from various precursors such as:

- sodium chlorite and hydrochloric acid,
- sodium chlorite and chlorine gas,
- sodium chlorite, sodium hypochlorite, and an acid,
- hydrochloric acid or sodium chlorate and hydrogen peroxide and sulfuric acid.

This process requires specialized equipment, and there have been concerns with worker safety in the past.

Chlorine dioxide does not form significant amounts of trihalomethane by-products and is equally effective at all pH levels. The by-products generated in the breakdown of chlorine dioxide in aqueous solution consist primarily of chlorite, chlorate, and chloride. The maximum contaminant level for chlorite is 1.0 mg/L. Chlorate has a notification level in California of 0.8 mg/L. Experience has shown that approximately two thirds of the chlorine dioxide added to water transforms to chlorite. Therefore, a chlorine dioxide dose less than 1.4 mg/L is considered the maximum to prevent formation of chlorite in concentrations greater than 1.0 mg/L.

In terms of mitigation efficacy, differing opinions exist in the relevant research. Van Benschoten et al. (1993a) reported chlorine dioxide to be less effective for veliger control than chlorine or chloramines. This is in contrast with other studies that concluded that chlorine dioxide was more effective at causing adult mortalities than chlorine. A number of facilities in Europe use chlorine dioxide for macrofouling control on freshwater and seawater systems. European experience suggests that continuous treatment of seawater with chlorine dioxide concentrations of 0.1 parts per million (ppm) eliminated biofouling in cooling systems. Rusznak et al. (1995), working with veligers and settled pediveligers, observed 95 percent reduction in settlement when chlorine dioxide was applied for 15 minutes every 6 hours at a concentration of 0.25 ppm.

Chlorine dioxide was selected as a Candidate Control Method. Pilot testing is needed to establish concentrations and contact times to meet the District's objectives.

3.1.4 Ozone

In practical applications, ozone has performed remarkably well in controlling dreissenid infestations. In Canada, ozone treatment is currently being used in an electricity generating station on Lake Ontario to prevent biofouling of secondary raw water systems. Ozone is injected at the start of the system at 0.3 to 0.5 mg/L continuously throughout the mussel breeding season. At that location, ozone has provided excellent control of all biofouling, including the prevention of zebra mussel settlement. It has also eliminated any adults which had previously settled in the system prior to the installation of the ozone generator.

This data mirrors an experience in Belgium (Verelst et al., 1999) at a power plant on the river Meuse. At that installation, ozone was injected at the level of 0.3 to 0.5 mg/L. This treatment achieved complete control of Asian clams and zebra mussels, as well as bacteria and algae in the secondary cooling system. The discharge into the river had less than 10 µg/L of residual ozone. Significant mortality of adults was observed after 20 days of exposure, with complete mortality achieved in 48 days.

Costs associated with ozone are very high, and there are other disadvantages, including the potential formation of bromate and/or assimilable organic carbon and the potential for corrosion of the pipeline.

Ozone was selected as a Candidate Control Method because it has a positive track record for controlling invasive mussels.

3.1.5 Ferrate

Ferrate is the anion, FeO_4^{2-}, in which iron (Fe) is in a +6 formal oxidation state (Fe VI). Fe (VI) reportedly has the highest reduction/oxidation potential of any common oxidant. Treatment by Fe (VI) reportedly does not yield any mutagenic/carcinogenic by-products, and the final product of Fe (VI) reduction is a non-toxic compound (Fe^{+3}, or Fe III). Within minutes of dilution in water, ferrate oxidizes other constituents in the water and reverts to Fe (III) which then combines with hydroxide ions to form iron-oxide precipitate. These substances naturally and abundantly present in rivers lakes and streams.

In the 1970s, ferrate was explored as a replacement chemical for chlorine, but synthesis methods at that time made its use cost prohibitive. Recently, Ferrate Treatment Technologies, LLC (FTT) has patented a new manufacturing process that reduces ferrate production costs. The Ferrator® is a transportable on-site synthesis reactor that produces Fe (VI) in a liquid form that can be directly injected into standard industrial treatment processes.

Many field trials with the Ferrator® have focused on ballast water treatment. Four ship trials were conducted at ports including Singapore and Rotterdam. Tests confirmed complete inactivation of microorganisms at 2 to 4 mg/L Ferrate following a 50 micron filter.

A laboratory study performed by FTT in 2008 and 2009 examined the potential usefulness of ferrate in the eradication or control of quagga mussel embryos (hours old) and veliger larvae (4 days old) (Johnson, 2009). Separate populations of embryos and larvae were treated with ferrate at varying concentrations in 500 milliliter (mL) containers of pondwater. All treatments of ferrate, including the lowest dose (1 mg/L), resulted in 0 percent survival of embryos and veliger larvae, while the control populations yielded 53.5 percent survival for embryos and 100 percent survival for veliger larvae.

At higher concentrations, ferrate may behave similar to ferric chloride (or other coagulants/flocculants) in terms of its coagulation properties, and therefore may end up contributing chemical sludge to the reservoirs. Ferrate also reportedly behaves similarly to anti-corrosion control chemicals, and may result in development of a thin film on the interior of pipelines.

Ferrate has been selected as a Candidate Control Method. But while ferrate shows great promise, it has not been used to date for mussel control on a commercial or industrial scale. Pilot testing is needed to establish concentrations and contact times to meet the District's objectives. Furthermore, ferrate has not been used for drinking water applications in California. Use by the District would be dependent on approval by the California Department of Public Health and the Regional Water Quality Control Board. FTT has National Sanitation Foundation (NSF) certification for their product.

Ferrate could be injected upstream of the Santa Clara Flow Meter Vault to be part of a protection strategy for the SBA and injected upstream of the PPP (in the intake tunnel or at the surge tower) to be part of a protection strategy for water from San Luis Reservoir. Diffuser piping would be used to ensure adequate mixing. Further mixing would occur at any downstream pumps.

Ferrate would be generated onsite with a Ferrator® system and three feed chemicals: sodium hypochlorite, ferric chloride, and sodium hydroxide (caustic soda). The system would require pumps, piping, and storage for each of the feed chemicals and the generated ferrate.

3.1.6 Bromine

Bromine can be used in several different forms as an antifouling agent. These various forms include activated bromine, sodium bromide, bromine chloride and proprietary mixtures of bromine and chlorine or other chemicals.

The breadth of research available for treatment using chlorine is not as readily available for bromine or bromine based products. Research conducted on zebra mussel veligers from Lake Erie found that bromine (0.5 mg/L) is not nearly as effective a settlement inhibitor as chlorine (Bidwell, 1993 and Bidwell, 1999).

Extra bromide in the water supply would be undesirable with ozone treatment (such as that at PWTP and STWTP) due to the formation of bromate upon subsequent ozonation in the plants. For these reasons, bromine was not selected as a Candidate Control Method.

3.1.7 Hydrogen Peroxide

Hydrogen peroxide has been used as an algaecide or biocide and has the reputation of being a benign oxidizing agent, dissociating into hydrogen and oxygen and leaving little or no detrimental environmental by-products behind. Several trials on both adult zebra mussels and veligers have shown that relatively high doses of hydrogen peroxide are required to induce mortality, 6 to 12 mg/L (Martin et al., 1992; Klerks et al., 1993). In two comparison studies versus chlorine and ozone, Van Benschoten (1991, 1993a, 1993b) found hydrogen peroxide to be successful, though not nearly as effective or efficient a mitigator as the other oxidant options. Petrille and Miller (2000) recorded 90 percent mortality rate of adult zebra mussels in 21 days of exposure at 5.4 mg/L concentration. The duration of the treatment could be shortened with increasing hydrogen peroxide concentration, but there may be regulatory limitations with measurable hydrogen peroxide residuals.

Hydrogen peroxide is more expensive than sodium hypochlorite. Therefore, it would not be a preferred control method unless chemical DBPs related to chlorine were considered problematic. Hydrogen peroxide doses for quagga and zebra mussel control are not well defined. Due to the high cost and lack of information on effectiveness, hydrogen peroxide was not selected as a Candidate Control Method.

3.1.8 Potassium Permanganate

Potassium permanganate is another oxidizing chemical commonly used in municipal facilities for water purification. It is widely utilized to oxidize iron and manganese and to control taste and odor problems. Some studies suggest that it can be used against adult zebra mussels, although it is less effective than chlorine. In flow-through experiments, Fraleigh et al. (1993) found that 0.25 mg/L of potassium permanganate prevented settlement of zebra mussels in testing tanks. In static experiments, Klerks et al., (1993) found less than 30 percent mortality in veligers exposed to 2.5 mg/L of permanganate for three hours. San Giacomo and Wymer (1997) found effective control of adults at a concentration of 2.0 mg/L, and veliger settlement was prevented using a concentration of 1.0 mg/L. These results suggest that potassium permanganate may prevent the settlement of mussels, but that it is not acutely toxic to either veligers or adults. The Paul M. Neal Water Treatment Facility in Lake Bluff, Illinois has employed the use of potassium permanganate at the intake structure on Lake Michigan, successfully preventing mussel settlement in the 2 miles of piping leading to the treatment facility for several years (Van Hemert, 2007).

Utilizing potassium permanganate as a mitigation strategy seems most applicable in potable water treatment facilities, especially considering that many already utilize this chemical for oxidation of taste and odor compounds as a substitute for pre-chlorination or to reduce chlorine demand and dose. Potassium permanganate concentrations must be limited to a concentration that would maintain a filtration plant residual level of less than 0.25 mg/L in order to prevent pink discoloration of potable water. The most important factors to consider when contemplating treatment using potassium permanganate are the cost of the chemical, solubility of potassium permanganate in the water and the size of the delivery.

At a practical concentration for use in the District system, potassium permanganate is unlikely to kill 100 percent of veligers. While the chemical could be used at a minimum concentration of 1 mg/L to prevent settlement in the raw water distribution system, it seems impractical and undesirable to maintain this concentration in the local reservoirs. Therefore, it is not a good candidate to prevent infestation at the reservoirs and was not selected as a Candidate Control Method.

3.2 Control Methods That Involve Non-oxidizing Chemicals

A number of non-oxidizing chemicals have been developed for bacterial disinfection and algae control and have also been tested as molluscicides. The main concern with these products is their persistence in the environment and water supply after being discharged. Those that have been registered are used primarily for end of season or periodic treatments. This is due in part to the expense of the chemicals, partly to the need to detoxify the outfall in some cases, and partly to lack of empirical data on the practical effect these chemicals have on veliger settlement.

3.2.1 Proprietary Molluscicides

The term molluscicide is actually a misnomer as generally these products are toxic to a wide variety of species and not just molluscs. All of these products have been shown to cause significant mortalities in adult dreissenid mussels. Their use within closed systems is unrestricted. In once-through applications, most of the products have to be detoxified with the addition of bentonite clay slurry.

Proprietary molluscicides would have to be removed before water could be stored in a local reservoir. Consequently, proprietary molluscicides were not selected as a Candidate Control Method. It may be possible, however, that proprietary molluscicides could be used by the District for difficult situations in limited segments of the system and for limited time durations.

3.2.2 Mexel®

The Mexel® line of products represents multipurpose water treatment technology. Mexel products consist of filming aliphatic amines which are able to inhibit corrosion, prevent slime and scaling and various forms of macrofouling. The active ingredient in Mexel is an alkyl trimethylenediamine, which is not a mortality-inducing agent but rather a repellant of unwanted organisms. Mexel was found to inhibit the formation of byssal threads of dreissenid mussels at concentrations of 2, 6, and 10 mg/L. These concentrations were also found to cause mortality in the mussels after 30 days of exposure. When added at the water intake point, typically once a day for 30 minutes at a level of 4 to 5 mg/L, it has been reported to keep all treated systems free of dreissenid mussels. At low concentrations, Mexel® does not require detoxification on discharge.

From review of the company's website (www.mexelusa.com), Mexel® appears to have been used for control of mussels only in power plant cooling water systems and not drinking water applications. Consequently, Mexel® was not selected as a Candidate Control Method.

3.2.3 Bacteria-Based Molluscicide

Marrone Bio Innovations, Inc. (MBI) of California is working on the development of Zequanox^{TM}, a microbial-derived product to control quagga and zebra mussels. The ability of *Pseudomonas fluorescens* (*P. fluorescens*), a common soil microorganism, to kill zebra and quagga mussels was discovered and patented (US Patent 6,194,194, 2001, D. Molloy) by the New York State Museum. Extensive bench and pilot scale studies have been conducted by the New York State Museum demonstrating the effectiveness of *P. fluorescens* in killing invasive mussels. Preliminary evaluations indicate that Zequanox^{TM} is effective at both preventing veliger settlement and killing adult mussels.

Toxicology studies have demonstrated that this product, as well as other products derived from different strains of *P. fluorescens*, are non-toxic and safe for use in agriculture products for human consumption. Toxicity testing included, but was not limited to, single dose acute toxicity treatment of ciliates, freshwater shrimp, daphnids, fathead minnows, bluegill sunfish, brown trout, blue mussels, and unionid clams. Zequanox^{TM}, at the maximum doses that would be applied to treat invasive mussels, was non-toxic to all of these organisms.

Major potential benefits of this product include:

- Zequanox^{TM} is a non-toxic natural product and therefore limits safety concerns related to handling, and

- Zequanox^{TM} does not form disinfection by-products.

Furthermore, Zequanox^{TM} is non-toxic and specifically targets invasive mussels. It does not impact native bi-valves and could therefore potentially be applied from source to treatment plant, allowing agencies to use one control method at multiple locations within their raw water systems. Two products are being developed - one for settlement prevention and one to kill settled adults. MBI will continue to develop a product that can be used in source waters, in conveyance structures that are released into open water reservoirs, and within facilities.

The impact of Zequanox^{TM} on downstream drinking water quality has not been evaluated; however, according to the product development objectives, Zequanox^{TM} should exhibit the following characteristics:

- A neutrally buffered product,

- A low contribution of additional organic carbon to source waters, and
- Any residual that exists should be easily removed during conventional treatment.

MBI has conducted a number of trials in domestic water and cooling water service lines at hydropower dams in the United States and Canada. Successful closed system field trials have been performed by MBI using bioboxes fabricated and installed by the United States Department of the Interior, Bureau of Reclamation (Reclamation) at Davis Dam, Bullhead City, Arizona, on the Colorado River (Reclamation, 2011). These trials have shown that Zequanox treatments result in adult quagga mussel mortality rates greater than 90 percent. Other research has demonstrated that at lower doses the product is effective in treating juvenile mussel stages and preventing their settlement (Reclamation, 2011). Jar testing, biobox, and full-scale trials were performed at Ontario Power Group DeCew Power Generating Facility in Ontario, Canada in 2009 and 2010. A commercial-scale trial is planned for July 2011 with a new commercial prototype.

MBI has received experimental use permits for the use of Zequanox™ at these facilities and other facilities. Reclamation has received a United States Environmental Protection Agency (EPA) Federal Insecticide, Fungicide, and Rodenticide Act Section 18 emergency exemption for limited use of Zequanox™ at Reclamation facilities and Bureau-managed water bodies. EPA is currently reviewing research on Zequanox™ for full product registration under Section 3 of FIFRA as a commercial molluscicide (Reclamation, 2011). Zequanox™ will not be commercially available locally until it is approved by all applicable regulatory agencies. MBI has initiated discussions with the California Department of Public Health.

Bacteria-based molluscicide was selected as a Candidate Control Method. Zequanox™ could be applied at one or multiple locations (e.g., in the source water reservoir, along the conveyance route, and the local reservoirs) without posing the environmental concern that chlorine would.

3.2.4 BioBullets

Most molluscs are able to sense chlorine as well as a number of other oxidizing chemicals and toxins. When they detect a noxious substance, they respond by closing their shells and isolating themselves from the irritant. Depending on the ambient temperature, the shell can remain closed for up to three weeks. Aldridge et al. (2006) has developed a method to encapsulate the active ingredient for mussel control in an "edible" coating. The individual particles are of the size commonly fed on by dreissenids (approximately 20 microns (µm)). The mussels filter these particles from the water and, due to the coating, they do not detect the active ingredient and as a result do not close their shells, passing these particles on to their digestive systems. Thus, the BioBullet overcomes the protective reaction that mussels have to noxious substances. Another added advantage to this application strategy is that much more of the active ingredient is filtered out by the mussels and therefore less of it ends up in the environment (though all that is not ingested by mussels is released into the environment). Potassium chloride has been used as a core of the BioBullet, as well as some proprietary chemicals.

BioBullets can be used only to control adult mussels, as they have to be able to eat a 40-micron sphere. They have no impact on veligers. Because this control method does not prevent veligers from reaching local reservoirs, it was not selected as a Candidate Control Method.

3.2.5 Ammonium Nitrate

At concentrations of 400 to 500 mg/L, ammonium nitrate has been reported to cause 100 percent mortality of adults in 5 to 6 days. The ambient temperature was 61 to 67 degrees Fahrenheit (°F) (16.1 to 19.4 degrees Celsius (°C)). Coon et al. (1993) report that ammonia concentrations exceeding 3 mg/L cause 100 percent mortality in veligers. This treatment strategy is not feasible for once through systems because of high concentrations of ammonia in the water being served, but it could be used within a closed loop and also in agricultural circumstances where chemical fertilization is already being utilized. It does not appear to offer any advantages over the commercial molluscicides mentioned above aside from the fact that is slightly cheaper.

Ammonium nitrate would have to be removed before water could be stored in a local reservoir. Consequently, it was not selected as a Candidate Control Method.

3.2.6 Copper Sulfate

Limited studies and field applications indicate that copper sulfate may be an effective control method for larval and adult dreissenids. Kennedy et al. (2006) determined that 14 to 81 μg/L of copper ions caused virtually complete mortality in zebra mussel veligers within 24 hours. The copper was added both as copper sulfate and as the copper rich algaecide Cutrine-Ultra®. In October 2008, a collaborative effort involving many governmental and environmental agencies (including the EPA, the US Army Corp of Engineers and the Nebraska Game and Parks Commission) was undertaken to completely eradicate zebra mussels from Offut Base Lake in Nebraska. A strategy was devised utilizing copper sulfate pentahydrate as the control method and a total of 27,000 pounds of the substance was applied to the surface of the lake in aqueous format via vortex spreaders on pontoon boats. Although long term studies will be required to assess the survival of the mussel population, at this time it is believed that a 100 percent mortality rate was achieved. The impact on native fish and wildlife species was not intended to be a significant component of the study; however, rough data obtained by the field teams showed a direct impact on 14 species of fish, with approximately 29,000 pounds of dead fish washing up on shore (Morris, 2008).

Copper sulfate is currently added to water in the SBA by the California Department of Water Resources (DWR) for control of algae. In 2009, copper sulfate was applied for a 2.5- to 3-hour duration approximately once or twice per month from March through October. A similar application schedule has been followed in 2010. Copper sulfate is applied at three locations in order to achieve a downstream concentration of 0.3 to 0.6 mg/L four miles from the last point of application (personal communication with Jeff Janik, 10/4/10).

Although DWR's application schedule could potentially kill some mussels, should they enter the SBA, it would not protect the system between applications. Continuous dosing would be required to protect downstream segments of the system that do not regularly receive high enough concentrations of copper ions, including local reservoirs where SBA water is stored. Continuous dosing of copper sulfate is not recommended, due to the high cost of copper sulfate and the potential impacts to other species in the local reservoirs. And, because of these environmental concerns, other control methods (such as potassium salts or pH adjustment) are preferred for reactive treatments. Consequently, copper sulfate was not selected as a Candidate Control Method.

3.2.7 Potassium Salts

Potassium compounds are toxic to most bivalves, including dreissenids. In flow-through experiments, Fisher et al. (1993) found 50 mg/L of potassium chloride prevented settlement of zebra mussels in a test chamber. A chamber receiving concentrations of 25 mg/L had as much settlement as the untreated controls. In contrast, Lewis et al. (1996), also using flow through experiments in mussel-infested waters, concluded that at 20 mg/L potassium chloride caused 100 percent mortality in adults in 52 days while preventing any new settlement.

In 2006, an isolated quarry in Virginia was treated with potassium chloride, also known as muriate of potash, in order to eradicate an infestation of zebra mussels. 174,000 gallons of potassium chloride solution was added to the 180 million-gallon quarry over a 3-week period in January and February 2006. Complete mortality of all dreissenids occurred in 35 days.

Potassium salts have been considered for use as an eradication method at San Justo Reservoir.

In addition to causing mortality, potassium has been observed to prevent valve closure and reduced filtration rates (Wildridge et al., 1996). The ability to prevent valve closure suggests that combination treatments, using potassium chloride to inhibit valve closure followed by a toxicant, could result in quicker elimination of adults and less chemical used.

Although potassium compounds are non-toxic to higher organisms such as fish, the toxicity to native bivalves makes regulatory approval for use of potassium chloride in systems that discharge to surface water more difficult.

Potassium salts have been selected as a Candidate Control Method. Potassium chloride could potentially be used by the District for spot treatments of vulnerable equipment, proactive protection strategies, or for eradication in the raw water system or reservoirs, if regulatory approval could be obtained.

3.2.8 Sodium Metabisulfite

Dreissenid mussels are relatively intolerant of the low dissolved oxygen concentrations. Systems with less than 3 mg/L at 20°C would have little chance of mussels surviving. Dissolved oxygen concentrations exceeding 50 percent saturation seem to be required for sustained, healthy populations.

The use of sodium metabisulfite as a dechlorinating and an oxygen-stripping agent prompted speculation whether this chemical could be used effectively as a treatment for zebra mussels. Studies by Mackie and Kilgour (1992) showed that sodium metabisulfite by itself is not very toxic to zebra mussels. A minimum concentration of about 177 mg/L of sodium metabisulfite would be required to kill all adult mussels in closed systems. Below this level, toxic effects are absent. Anoxia caused by the addition of sodium metabisulfite will contribute to the mortality on prolonged exposure as sodium metabisulfite is an effective oxygen stripper. Depending on facility specific conditions, anoxic conditions combined with higher water temperatures will increase dreissenid mortality more than the effects of either alone (Matthews and McMahon, 1999; Yu and Culver, 1999).

Sodium metabisulfite is not considered to be a practically feasible chemical for eliminating mussels in pipelines or conduits because enormous amounts of the compound would be required for treatment. Consequently, sodium metabisulfite was not selected as a Candidate Control Method.

3.2.9 Coagulation / Flocculation

There have been several reports on the effect coagulants/flocculants have on zebra mussel veligers. Studies by Mackie and Kilgour (1995) investigated the effect of aluminum sulfate (alum) on zebra mussel veligers. From that study it would appear that the concentrations of alum used in most water treatment plants (i.e., 10-30 mg/L) is not sufficient to kill the veliger larvae by direct toxicity. In the laboratory studies, 130 mg/L of alum were required to cause 50 percent mortality of zebra mussel veligers in 24 hours. However, the data also indicate that a pH depression below 5, caused by the addition of alum, especially in the mixing zone, would cause an instantaneous kill of veligers. Further, the role of alum in removal of veligers under natural conditions (i.e., 10-30 mg/L alum) appears to be mainly a physical one, with the floc physically removing even living veligers. Most veligers remain alive for at least 24 hours in the floc at concentrations below 100 mg/L. Pre-chlorination greatly improves the efficacy of alum in removing veligers from raw water supplies, probably by aiding sedimentation of veligers by causing them to close their shells and increasing their likelihood of becoming part of the floc. In short, alum will remove veliger larvae by chemical toxicity in the mixing zones of alum and chlorine and by flocculation of both living and dead veligers in other areas.

It is assumed that use of coagulants and flocculation would be impractical to protect the raw water system and the local reservoirs (e.g., would result in coagulant sludge buildup in the system or reservoirs). Consequently, this was not selected as a Candidate Control Method. It should be noted, however, that the District's Page, Kirk, and Guadalupe recharge ponds include pretreatment with polymer before the water enters the pond. Some level of protection would likely be afforded to these ponds as a result of the polymer addition.

3.2.10 Salinity

The potential for use of salinity as a control strategy exists mainly in industrial facilities situated on the fresh water and salt water interface (e.g., lower Hudson). Kilgour and Keppel (1993) observed acute toxic effects on zebra mussel veligers at salinity levels above 8.5 parts per thousand.

This control method is considered incompatible with a drinking water supply system and was not selected as a Candidate Control Method.

3.2.11 pH Adjustment

pH is a limiting variable for dreissenid survival, and there is debate as to what pH level can be tolerated by larval stages and at what pH adults will survive for prolonged periods of time. The pH threshold value for survival of adults is above approximately 6.5 (McCauley and Kott, 1993); for larvae it is approximately above 6.9 (Mackie and Kilgour, 1993). At the other extreme, Bowman and Bailey (1998) note that almost 100 percent adult zebra mussel mortality could be expected when pH reaches 9.3 to 9.5.

Some systems naturally have a pH which is close to the limit of successful survival of dreissenid veligers. In such water bodies, it may be possible to adjust the pH of the raw water being withdrawn at the intake, thus protecting the intake pipes as well as all downstream systems that will contain water with a pH above or below the threshold tolerance levels.

Based on review of water quality data provided by the District, the median pH for raw water is 8.0 at PWTP and 7.6 at San Luis Reservoir. The median total alkalinity (as calcium carbonate) for raw water is 74 mg/L at PWTP and 83 mg/L at San Luis Reservoir. These values indicate that raising the pH of raw water above 9.3 for selected segments of the raw water distribution system may be economically feasible.

pH adjustment has been selected as a Candidate Control Method because it has the advantages of being relatively low in cost, simple to operate, and free of any disinfection by-products or other water quality concerns. pH adjustment could be accomplished with lime or sodium hydroxide addition at Santa Clara Flow Meter Vault and/or the intake tunnel between San Luis Reservoir and Pacheco Pumping Plant. This would affect the pH of water in the reservoirs and would also affect treatment plant operations. pH reduction, with sulfuric acid, carbon dioxide, or carbolic acid, would be required prior to treatment or discharge to storage reservoirs.

This control method could involve a continuous feed to prevent colonization within the system. It would likely require addition of another chemical (e.g., chlorine or ferrate) to quickly kill veligers for protection of local reservoirs. Alternatively, it may also be possible to use pH adjustment as a reactive treatment to kill settled mussels, whereby the pH in the area to be treated would be raised for approximately one month.

It is important to note that there is little or no industry experience with pH adjustment as a means of controlling dreissenids. If pH adjustment were selected as a protection alternative, bench-scale or pilot-scale tests to determine the effects of high pH on mussel mortality should be performed to demonstrate that zebra and quagga mussels cannot survive in water with pH above 9.3. More information on the duration of treatment needed to kill 100 percent of settled mussels is also desired. Bench-scale bioassays to test the effectiveness of pH adjustment would be simple and could be conducted in the field at a location that already has a mussel infestation. Reclamation will fund an experiment to be performed in the summer of 2011 to test the effects of high pH on adult mortality and downstream settlement.

3.3 Control Methods That Do Not Involve Chemical Addition

3.3.1 UV Irradiation

The use of ultraviolet (UV) radiation as a control method is appropriate for larval stages of mollusk macrofoulers which have transparent shells. It is used in the water treatment process to disinfect water by causing disruption of the tissue functions and damaging the DNA of living organisms.

UV light is classified as electromagnetic waves with a wavelength of 40 to 400 nanometers (nm) and is typically generated by applying voltage across a gas mixture. The wavelength and intensity of UV light is a function of the elemental composition of the gas mixture. UV disinfection systems used in water treatment systems use mercury vapor as the gas mixture, because mercury vapor emits UV light with optimum germicidal effects. The germicidal UV light wavelengths range from 200 to 300 nm, with the optimum germicidal effect occurring at 253.7 nm.

Studies completed in the late 1990s indicated that medium pressure lamps with UV wavelength between 200 and 400 nm delivering a dose greater than 100 millijoules per square centimeter (mJ/cm^2) are effective in mitigating mussel veliger populations.

The effectiveness of UV to kill quagga or zebra mussels depends on the wavelength, strength (intensity) and duration of contact in the areas to be protected. Based on work by numerous authors in the early 1990s, UVB and UVC wavelengths were found to be most effective for dreissenid veliger control. The basis for the control is thought to be the impact of the UV light on the essential functions of the veliger, thereby inactivating the organism and preventing attachment. The most effective wavelength and the radiation dose which the veliger must receive to experience either immediate or latent mortality has been the subject of numerous experiments. UVC in the range of 100 nm to 280 nm may be most effective for inactivation purposes.

Destruction of adult mussels with UV would require a much greater dose than would be used to kill or disable veligers. Therefore, UV could best be used as a method for inactivating veligers and would rely on screening or filtration to control adult mussels. Tests have shown that veligers that are not quickly killed by exposure to UV are damaged, do not mature into adults, and eventually die.

Wright and Dawson (2002) working on a ballast water system found that a dose of 200 mJ/cm^2 applied at a flow rate of 1,000 gallons per minute (gpm) would be effective in mitigating all aquatic biofouling downstream of a filter which removed larger organisms and sediment.

According to Renata Claudi (personal communication, October 7, 2010), the 2002 Wright and Dawson experiment used high doses to achieve rapid mortality, and a lower dose could possibly be used to achieve a similar level of protection. A full-scale UV system has recently been installed at Hoover Dam to test the effectiveness of UV irradiation to manage downstream mussel settlement and the results may help better define design criteria for control of mussels with UV systems.

The effectiveness of a UV system is dependent on the characteristics of the raw water being treated. Factors such as UV transmittance (UVT), presence and size of suspended solids, iron, manganese, hardness and temperature all affect the efficacy of the UV system. Treatment systems must be designed for the worst case scenarios. This means designing for peak flows, end of lamp life intensity, minimum transmittance and maximum suspended solids at the installation location. The aim of the system is to achieve 100 percent immediate or latent mortality in all veligers which pass through. If an adequate dose is not delivered at this point, downstream settlement could occur, as UV-based systems have no residual toxicity which could impact areas outside the influence of the lamps (Mackie and Claudi, 2010).

UV radiation was selected as a Candidate Control Method, largely because the formation of disinfection byproducts is minimal. UV reactors would be most efficient if installed after mechanical filters (see Section 3.3.4). If this control method was selected, a possible design would involve one UV unit following a mechanical filter on each line of a manifold installed at the Santa Clara Flow Meter property or the PPP.

UV systems would have to be designed such that each line could be shut down for routine maintenance. Measures would have to be in place to prevent untreated water from passing through the system in the case of a power outage or other failure.

According to results of water samples collected from the Pacheco Intake (San Luis EROP Portal) from 2003 to 2004, the following UVT statistics apply:

- The minimum UV254 absorbance was 0.072 per cm, which equates to a UVT of 84.7 percent
- The median UV254 absorbance was 0.1035 per cm, which equates to a UVT of 79 percent
- The maximum UV254 absorbance was 0.12 per cm, which equates to a UVT of 75.9 percent

UV254 absorbance measurements performed by DWR at Banks Pumping Plant from 2005 through 2010 are similar, with minimum, median, and maximum UVT values of 52, 80, and 93 percent, respectively.

These UVT values are somewhat low and indicate that UV irradiation of water from San Luis Reservoir would require more power to achieve the same dose as a typical drinking water installation.

3.3.2 Infiltration Gallery

One technology which offers fail-safe, full system protection is an infiltration gallery. Several different designs exist, but ultimately they all act as either a slow or rapid sand-filtration system. The infiltration system draws water through porous layers created out of different materials, eliminating progressively smaller particles as the water moves through. Maintenance of the system is done either through a backwash system or a periodic removal of the top layer by mechanical means.

It is assumed that an infiltration gallery would be prohibitively expensive to incorporate into the District's raw water distribution system, and therefore this technology was not selected as a Candidate Control Method.

3.3.3 Media Filtration

Another fail-safe, full system control method could involve a conventional filtration system, such as those that are present at each of the District's three water treatment plants.

It is assumed that a conventional filtration system would be prohibitively expensive to incorporate into the District's raw water distribution system, and therefore this technology was not selected as a Candidate Control Method.

3.3.4 Mechanical Filtration

Mechanical filtration technology (aka, self-cleaning, small-pore filters and automatic filters) can be used to remove most life stages of zebra and quagga mussels. Several manufacturers design filters capable of removing particles greater than 20 µm from large volumes of water while experiencing a minimal pressure drop on the system. In addition, these filters are capable of automatically removing filtered debris that accumulates on the filter screen while the filter continues to perform its function.

A physical barrier to adult mussels may be desired for the following reasons. Adult mussels, particularly very small, recently settled individuals, frequently become detached and are carried with water flow to new locations. These translocating individuals have robust shells, not easily breached by most chemical treatments. If such individuals are not excluded from the pipeline, they may become established within the raw water distribution system or the reservoirs. Continuous chemical treatments, which may be used to control the larval stages, might not be sufficiently effective against established adults.

Mechanical filters were selected as a Candidate Control Method. The following sections, summarized or reproduced from *Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems* (Mackie and Claudi, 2010), provide more information for consideration of filter equipment.

Filter mesh

Automatic filters often use woven mesh with very uniform square openings. This type of screen is sometimes referred to as “Weave Wire.” This screen design is highly suitable for the removal of suspended organic matter.

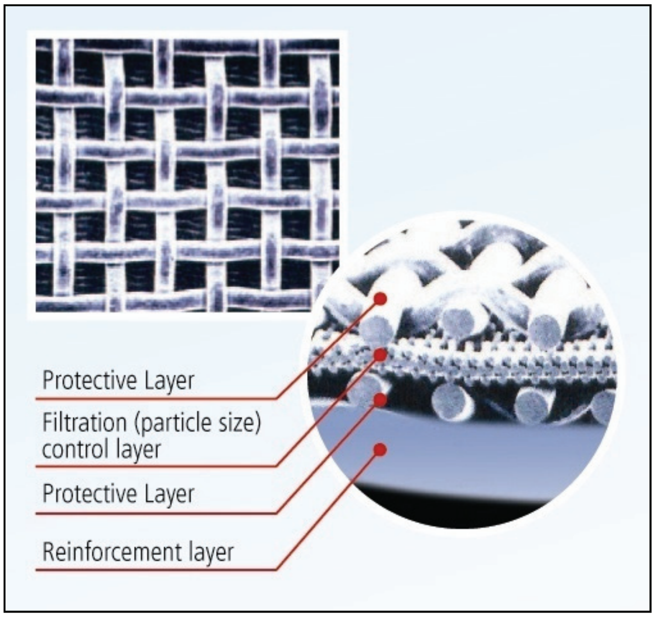
Many filters are very good at removing all or most particles from the water stream but high sediment loads can prevent filters from processing large volumes of water efficiently. Filters which use stainless steel, square weave mesh and periodic backwash seem to have the best balance between particle removal efficiency and volume of water filtered. A number of manufacturers produce such filters, but the evaluation process of individual units can be confusing. Some manufacturers do not distinguish between nominal and absolute size of the pores in the mesh they offer. It is important to understand the difference.

There are various test methods used to establish the absolute size of pores in woven wire cloths. The absolute mesh size rating corresponds to the diagonal length of the filter pore. For example, a 40 micron mesh will have a diagonal of 57 microns which would correspond to the absolute size rating.

Nominal value, on the other hand, is an arbitrary term generally corresponding to removal of 98 percent of all incident particles larger than the size given. Various methods are used to determine the nominal rating and the reproducibility using these methods is poor. Therefore, it is advisable to determine the quality and the absolute mesh size rating the filter manufacturer is offering.

Smythe et al. (1993) reported on the performance of the Kinney Strainer (equipped with a 40, 95 or 142 nominal µm mesh) and the Bromm Filter (nominal mesh size 60 and 100 µm). Although the Kinney Strainer (40 nominal µm mesh) and the Bromm Filter (60 µm nominal mesh) reduced the densities of ready-to-settle veligers (>250 µm) in the filtrate by up to 97 percent, they did not totally exclude all individuals from the system. Examination of the mesh used in each case revealed that the nominal micron ratings were not reliable indicators of the largest opening found in the mesh.

In order to have as much open area as possible in the mesh, the wires used to create the mesh tend to be very thin. This means that, unless the mesh is properly supported, the individual pores may be distorted by pressure, and the cloth may be torn by the backwash system. Strong support of the screen to prevent distortion and tearing is essential. Three to four layers of "sandwich" is recommended. The various layers should be sintered together for best support and performance.



Source: BallastSafe Filter Company

Figure 3-1. Layering of the Filtration Mesh within Reinforcement

Even great quality wire weave mesh will allow some organic particles greater than the absolute micron size. During recent filter trials, it was noted that a 120- µm absolute mesh allowed some 200- µm veligers through. A 57- µm absolute screen passed through some 100- µm veligers.

Industrial filters using slot-shaped filter media, referred to as "Wedge Wire," have been found to be incapable of preventing larval stages of dreissenid mussels from entering cooling water systems. This is due to the fact that wedge wire type screen filters are designed to remove inorganic matter such as quartz or metal shavings, but they have difficulty stopping organic matter from passing through the screen. This is due to the flexible nature of the organic matter which tends to "sneak through" the wedges of the screen. This type of screen should be avoided for control of mussels, as it will occasionally even allow small adults to push through.

Construction

Sturdy materials of construction are a must. Plastic parts generally do not stand up to the rigors of industrial application. Excellent sealing between filter components is required to prevent water interchange between filtered and non-filtered water in different chambers.

Information received from three manufacturers of automatic filters is included in Appendix A.

Backwash system

Automatic filters are capable of remaining in service while a portion of the filter is backwashed. To do so, there must be a differential pressure of at least 21 to 28 pounds per square inch (psi) (depending on the filter manufacturer) between the filter outlet and the backflushing line. The backwashing processes for three manufacturers of automatic filters are described in the brochures included in Appendix A.

The more water a filter uses for backwash, the less there is available for application use. Under normal conditions, 1 to 3 percent of the total filtered flow is required for backwash. This percentage increases proportionately as the Total Suspended Solids (TSS) load increases. Product data curves for maximum flow at a range of TSS concentrations were not available from the filter manufacturers at the time of this writing, but should be requested prior to design and/or selection of a specific automatic filter make and model.

The filter should be capable of backwashing both based on time elapsed and on differential pressure across the screen. The greater the differential pressure across the screen, the more likely it is that soft organic material will be forced through. A differential of no more than 3 to 5 psi is generally recommended.

In addition to removing all larval stages of macrofoulers, filters remove substantial portions of particulate matter, such as sediment. How much they remove is a question of mesh size and size distribution of the particulate matter in the water column. At one installation, it was estimated that an automatic filter installed on a system carrying 1,000 gpm of water removed over 10,000 kilograms of silt each year.

Filtration systems are not appropriate for water streams with continuous, high sediment load. Under such conditions, the backwash system may not be able to remove the sediment cake which builds up on the screen and up to 30 percent of water filtered may be lost as backwash.

Field Installations

Operating experiences suggest that parallel arrangement of multiple units is a must if filtration is to be considered as a viable control measure for industrial systems. For example, two filters, each capable of filtering 100 percent of the flow would represent a guarantee that only filtered water reached downstream systems.

The State of Vermont has used automatic filters for zebra mussel control at the Edgar Weed Fish Culture Station facility in Grand Isle, Vermont since 1996. The design of the hatchery took advantage of a cold deep-water inlet and a warm shallow-water inlet in Lake Champlain for efficient water temperature control. Problems began when zebra mussels infested the shallow-water inlet. To allow the use of both water inlets for efficient temperature control required the design of a mechanical filtration system with stainless steel weavewire screens rated at 40 microns (absolute) to assure the prevention of any life forms of zebra mussel from infiltrating the hatchery. The system had to handle a maximum flow rate of 8,800 gpm. The designed system consisted of nine 10-inch automatic self-cleaning screen element pressure filters operating at 21 psi. According to a 2003 abstract for the 12th International Conference on Aquatic Invasive Species written by Amiad Filtration Systems, no zebra mussels had been detected in the treated hatchery water (Allhands, 2003).

East Bay Municipal Utility District staff contacted staff at Vermont Fish and Wildlife and Edgar Weed Fish Culture Station in September and October 2009. Kevin Kelsey, Vermont Fish and Wildlife, said the Amiad filters work well when running. But the hatchery water supply for Edgar Weed Fish Culture Station has wide swings of TSS, and when it becomes turbid, they experience rapid clogging of the screens and the water delivery system becomes inoperable.

In the fall of 1999, a full scale filter experiment was set up at the Nanticoke TGS by Ontario Power Generation. The automatic filter, equipped with a 40-micron absolute woven mesh was installed downstream of an automatic wedge wire strainer with screen gaps of approximately 3 mm. The designed filter capacity was 12,000 gpm, but the system was typically run at 6,000 gpm. Backwashing cycles were typically triggered hourly. During a backwashing cycle, the water flow would drop down to approximately 4,500 gpm. The system ran well when total solids loading was mostly 15 mg/L or less. When the solids loading rate reached 60 to 80 mg/L, the filter was able to handle this loading, but it had to backwash almost continuously. It was concluded that the system would break down when the total suspended solids exceeded 80 mg/L.

The filter achieved removal of 95.9 to 100 percent removal of veligers. The veligers that did pass through the system were all dead. The downstream biobox sampler was free of any adult settlement at the end of the experiment, while the biobox placed upstream of the filter had hundreds of settled mussels.

Applications at the South Bay Aqueduct and Pacheco Pump Plant

Mechanical filters could be installed on District property near the Santa Clara Flow Meter Vault to be part of a protection strategy for the SBA. Application would require diversion of flow through several filters in parallel. Depending on the system pressure at Santa Clara Flow Meter Vault, pumps may have to be installed along with the mechanical filters.

Mechanical filters could be installed downstream of the pumps at the PPP. The discharge header could be manifolded to install several filters in parallel. The pressure in the line between the PPP and the regulating tank (at a normal operating elevation of 632 feet in the tank) is 33 psi.

In order to remove juveniles, adults, and shells, the filter should be designed to remove all particles greater than 200 micron. An absolute pore size of 120 to 150 micron is recommended for this application.

The anticipated headloss associated with mechanical filter systems at the maximum system flow ranges from approximately 2 to 10 feet.

Because the screens would be installed downstream of the pumps, they would have to withstand the pump discharge pressures.

Information about typical and maximum TSS loads and particle size distributions is needed to properly evaluate the potential performance of mechanical filters. TSS and particle size distribution data were not available at the time of this writing. Representative data should be collected for raw water systems where mechanical filters are being considered.

Backwash Water Treatment and Solids Handling

Backwash water from the self-cleaning filters would be treated to remove suspended solids prior to discharge offsite. Lamella plate clarifiers may be used to remove suspended solids from the backwash water.

Effluent sludge flow from the lamella plate clarifiers could have a solids concentration of 1 to 1.5 percent. Gravity thickening or mechanical dewatering could be used to reduce truckloads and disposal fees. Gravity thickening could involve lagoon settling or a gravity thickener. Equipment options for mechanical dewatering include plate and frame filter presses, belt filter presses, screw presses, and centrifuges. Solids could be hauled by truck to a local landfill for disposal. Filtrate could be discharged with the clarified effluent from the lamella plate clarifiers.

Non-mechanical dewatering options, such as drying beds, could also be considered. However, drying beds would require greater footprint than mechanical dewatering, and extended rainfall can severely impact the performance of this unit process.

3.3.5 Membrane Filtration

Another fail-safe, full system control method could involve a membrane filtration system. It is assumed that a membrane filtration system would be prohibitively expensive to incorporate into the District's raw water distribution system, and therefore this technology was not selected as a Candidate Control Method.

3.3.6 Antifouling and Foul-Release Coatings

Historically, the majority of developmental work in antifouling paints/coatings has been directed towards prevention of barnacle growth on ships. On external structures, coatings represent one of the best methods for minimizing the fouling and minimizing the need for mechanical cleaning.

Copper-based antifouling coatings have been used successfully for number of years, but leaching of copper ions may result in unacceptable concentrations of copper concentrations in the discharge water.

Foul-release coatings form a physical barrier to attachment. Silicone-based paints which prevent or greatly decrease the strength of attachment have been used with success. Re-coating is generally required every 5 to 10 years. The silicone based coatings usually require several different layers to be applied to a clean, white metal surface or very clean and almost dry (10 percent or less moisture level) concrete. To be allowed in potable water supplies, the antifouling coatings must be NSF 60 or 61 certified.

Although not practical for pipelines, coatings have been selected as a Candidate Control Method to protect equipment that are upstream from other control methods. Coatings may be appropriate for use as part of new intake grates in San Luis Reservoir. Soft silicone coatings, such as those made by Kansai Paint, Chiguo, and International Paint, have proven to be effective in the Great

Lakes. Reclamation has been performing testing of metal alloys and protective coatings for their effectiveness at resisting fouling, and the results should be reviewed prior to selecting a coating.

3.3.7 Speed of Flow

When the speed of flow in a raw water system exceeds 5 feet per second (ft/s), there is minimal, if any, settlement observed. However, that velocity needs to be maintained continuously.

High speed of flow does not prevent invasive mussels from settling and surviving in other parts of the system where flow speed is decreased. Speed of flow greater than 5 ft/s may already exist in some District piping systems and components by original design. However, changing the design of other piping systems to increase flow speed would be costly in capital costs and operating costs. Therefore, this control method was not selected as a Candidate Control Method.

3.3.8 Electric Currents

Electric current can be used in a flowing stream of water to shock and disable incoming veligers, or it can be used to create an electrical field on or just above a substrate to prevent the settlement of macrofoulers. In experiments aimed at veliger destruction, veligers, postveligers, and juveniles were killed when passing through a strong electrostatic field. The literature suggests that successful mitigation requires either a very high electrical intensity and short exposure or a longer exposure time at lower intensity to achieve the desired effect.

When using electric currents to protect surfaces from settlement, a field study in 1993 suggested that electric current densities commonly used for protection of steel surfaces against corrosion in freshwater environments deterred zebra mussel settlement. Significant reduction in settlement was accomplished at 6-9 milliamps per square-foot as compared to the control group (Lewis and Pawson, 1993).

Electrodes installed at the Nanticoke Thermal Generating Station on both concrete and steel panels found that when using 20 volts and 1.52 and 1.88 amps, no mussels settled on either electrified surface, while the control panels contained mussel densities of 2,877 per meter (Fears and Mackie, 1997). In a similar study, complete prevention of settlement was achieved on both steel and wood surfaces with a voltage of 3.15 volts per cm (Fears and Mackie, 1995).

Based on the voltages necessary, the required length of exposure, and the amount of power needed, this technique of control would be impractical for most industrial applications. This control method was not selected as a Candidate Control Method for this reason.

3.3.9 Acoustics

Although the use of sound as a deterrent to mussel settlement is frequently mentioned, the research performed in this area has often been inconclusive or impractical, possibly because of the difficulty of effectively measuring, installing, and reliably operating some types of the sound-generating devices proposed.

Sparker technology is an acoustic method that can be used to prevent veliger settlement or to kill settled adult mussels. A plasma sparker device was used in several experiments and two field installations to produce an underwater pressure shock strong enough to cause incoming dreissenid veligers to close their shells and thereby prevent attachment. The sparker also causes settled adult mussels to close their shells, preventing feeding. Mussels near the sparker may crack and eventually disintegrate from repeated strong pressure pulses bombarding the mussel shell.

Sparker technology is based on a high-voltage spark passing between two electrodes submerged in water. The spark arcs repeatedly between the electrodes at a predetermined rate of seconds or minutes. The electrical discharge quickly vaporizes the surrounding water producing a plasma bubble (high-temperature gas/water vapor), a pressure wave, and a light pulse. The vapor-filled "bubble" expands and contracts, producing additional pulses. This expansion and collapse repeats until the energy in the cavity is dissipated. A reflector may be used to direct the pressure pulse into a pipe or toward an area to be protected from dreissenid.

Acoustic technologies, including sparker technology, would only be practical to protect small areas of the District's raw water system, if at all. For this reason, they were not selected as a Candidate Control Method.

3.3.10 Magnetic Fields

Several studies have been performed to determine whether a standing magnetic field can perceptibly affect mussel settlement and populations. Although no solid conclusions about the mechanism responsible for any magnetic effects can be confirmed at this time, the dominant theories maintain that either the magnetism causes soft tissue damage directly, especially to the gills (Barnes et al., 1998) or else that elemental uptake and availability of certain minerals (e.g., magnesium and calcium) may be impaired. The studies performed in this area have yielded mixed results.

Smythe et al. (1997) found no significant mortality or settlement inhibition after treating mussels with water which passed through a 3,000-gauss field. After 99 days, the treated mussels were not significantly different from the mussels in the control group in terms of mortality, shell length, or calcium-magnesium content in soft tissues. In 1998, zebra mussels were exposed in a closed system to water that passed through an induced electromagnetic field (Ryan, 1998). Mussels in this treatment died within 15 days or less. The loss of calcium by the mussels was thought to be the cause of mortality.

Because this control method is not fully developed, and has not proven to prevent invasive mussels from entering the system or settling, this control method was not selected as a Candidate Control Method.

3.3.11 Mechanical Cleaning

Accumulated dreissenid mussel populations can be removed from all external structures and some large diameter piping by a variety of manual methods. This provides a short term solution which has to be repeated at regular intervals. Mechanical "pigs" or scrubbers have been used effectively to knock and scrape mussels and other debris from large-bore pipelines. Pigs are available in a wide variety of designs, and they are manufactured to clean pipes up to 70 inches in diameter. During cleaning, the pipeline is unavailable for normal service. Drinking water plant intakes are particularly suitable for this method. However, several plants have expressed concern that their structures may not be able to withstand the pressure generated by the mechanical pig on the pipeline.

Several diver-operated tools and techniques are available for underwater cleaning and new diver-operated tools are being introduced frequently. Various scrapers and brushes which are equipped with a vacuum generally work best for removal of shells. Remotely-operated tools have also been used for various underwater cleaning tasks.

Mechanical cleaning may be utilized as a routine maintenance measure upstream of other control methods. However, because it is a reactive strategy that does not prevent invasive mussels from entering the system or settling, and because it only periodically results in removal of mussels from a limited area, this control method was not selected as a Candidate Control Method.

3.3.12 High and Low Pressure Water Cleaning

Hydroblasting or hydrolasing has been used to remove corrosion products, unwanted coatings and biofouling. The area to be cleaned is generally dewatered and then cleaned with a jet of water. A variety of nozzle and hose configurations is possible, as is the combination of pressure and volume. The choice will depend on the personal preference of the user. However, the integrity of the surface being cleaned has to preserved and it is desirable to remove as much of the byssal thread and byssal pad as possible. Subaqueous high pressure water jet devices have been used in some cases.

Pressurized water cleaning may be utilized as a routine maintenance measure upstream of other control methods. However, because it is a reactive strategy that does not prevent invasive mussels from entering the system or settling, and because it only periodically results in removal of mussels from a limited area, this control method was not selected as a Candidate Control Method.

3.3.13 Thermal Shock

Hot water is very effective for killing mussels. 89.6°F for 48 hours has been determined to be a lethal thermal dose, as has 104°F for one hour. In between these values is a gray area where the exact temperature and time to death is dependent on number of factors. One factor is the acclimation temperature of the mussels (i.e., the ambient temperature of the water). The lower the acclimation temperature, the more susceptible the mussels are to thermal shock. Another factor is the rate of temperature increase. If the rate of increase is very gradual, the mussels may acclimate during the process and survive for a longer period than anticipated. Possible genetic variation in local populations also needs to be considered. It is possible that dreissenid mussels from a particular geographic area may be more temperature tolerant than mussels many miles away.

Griffiths (1992) and McMahon et al. (1993) have published tables and formulas, respectively, to predict the time to death for 100 percent of mussels.

Temperatures in the 90°F range applied for a few hours were successful in reducing mussel concentrations in Winnetka, Illinois.

Thermal shock is a reactive strategy that can be applied as a spot treatment method for very small plant utility systems, such as pump cooling lines or fire suppression systems, periodically when the system is not in use. This control method was selected as a Candidate Control Method for this purpose.

3.3.14 Desiccation

The drying process involves the draining of systems and subjecting the mussels to desiccation. However, a prolonged shutdown may be required. Mussels can survive considerably more than 10 days in a cool (below 59°F), moist environment (McMahon et al., 1992). In this same study, the author concluded that at 77°F, zebra mussels can survive for less than 150 hours regardless of relative humidity. At 95°F death occurred in less than 40 hours, particularly at high relative humidity. It appears that the inability to cool tissues through evaporation at high relative humidity accelerates mortality rates rather than the actual loss of water from the tissues.

Desiccation may be utilized as a routine maintenance measure at San Luis Reservoir or upstream of other control methods. Reservoirs that have large seasonal variations in water level will have a natural control of mussels that have settled on the exposed areas as the water level drops. This partial control will assist in reducing overall mussel density. However, because it can only be applied periodically and may have significant impacts to operations, this control method was not selected as a Candidate Control Method.

3.3.15 Oxygen Deprivation

This strategy could be accomplished by adding an oxygen scavenging chemical into a closed system or by keeping a system such as a pipeline static for a sufficient time period for biological oxygen demand to consume all available oxygen. Dreissenid mussels appear to be able to survive up to two weeks without oxygen in water, provided the ambient temperatures are low enough. Lack of oxygen can increase populations of sulfate-reducing bacteria, which may lead to corrosion problems. Because it can only be applied periodically and may have significant impacts to operations, this control method was not selected as a Candidate Control Method.

4.0 Protection/Mitigation Strategies and Alternatives

This section identifies and describes strategies for protecting District equipment and resources from invasive mussels, or mitigating the impacts caused by mussels. Alternatives are described and evaluated for their ability to meet different objectives.

This report groups invasive mussel prevention and control strategies into three categories:

- Long-Term, Full-Barrier Protection Strategy Alternatives
- Short-Term, Partial-System Protection Strategy Alternatives
- Reactive Mitigation Alternatives

Long-Term, Full-Barrier Protection Strategy Alternatives (Full-Barrier Alternatives) involve a combination of mechanical filtration with chemical addition or UV irradiation for a multi-barrier approach. The mechanical filtration component is for control of adult and juvenile mussels, and the chemical addition or UV irradiation is intended to kill or damage mussel larvae to prevent establishment of mussel populations downstream and outside of the influence of the protection strategy. The Full-Barrier Alternatives would be implemented in an attempt to prevent any viable mussels from passing beyond a designated control location within the raw water system. Meeting this objective would be protective of the downstream raw water system and receiving surface waters. It is important to note that 100 percent protection of the downstream system and receiving waters has never been attempted by a large water utility. The closest analogues are ballast water protection systems currently being tested. Mussel control methods have traditionally been implemented by utilities in response to infestations of mussels in their source water or system and have been designed to minimize the growth of mussels and/or mitigate the effects of mussels once they enter their system.

Full-Barrier Alternatives are very expensive and will require significant lead time to implement (estimated at 3 to 6 years). Consequently, Short-Term, Partial-System Protection Strategy Alternatives (Partial-Protection Alternatives) that could be implemented in less than 3 years are considered in this document. These alternatives involve pH adjustment or addition of chlorine, chlorine dioxide, or potassium to prevent settlement of mussels in protected segments of the system, and some elements of the Partial-Protection Alternatives may be compatible with the Full-Barrier Alternatives. Because these alternatives do not involve filtration, they are less protective than the Full-Barrier Alternatives, as some translocating juveniles and adults would likely survive the chemical treatments and could reach areas that are not protected. Some of the Partial-Protection Alternatives may also have greater impacts to water quality or the environment than the Full-Barrier Alternatives. Despite these drawbacks, they represent an improvement over the existing system in terms of protection from invasive mussels and minimization of impacts.

The Reactive Mitigation Alternatives should be considered if mussels become established in the District system downstream of the designated control locations. They consist of periodic treatments to reduce the populations of settled adults within the raw water system or reservoirs. Although these methods would not prevent mussels from entering the system and potentially settling in pipelines or local reservoirs, they may be part of a program to successfully maintain District raw water operations and to minimize impact to District water treatment facilities.

4.1 Full-Barrier Alternatives for the System Receiving SBA Water

Full-Barrier Alternatives for the District's raw water system receiving SBA water (SBA System) are listed in Table 4-1 and described in the following subsections.

Table 4-1. Full-Barrier Alternatives for the South Bay Aqueduct System

Full-Barrier Alternatives	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria	Data gaps
Alternative 1: Filters and UV	Mechanical Filters, UV Irradiation (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; UV dose: 100 mJ/cm^2	Required UV dose
Alternative 2: Ferrate and Filters	Ferrate, Mechanical Filters (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ferrate dose: 1 mg/L	Ferrate is essentially a new treatment for the water industry. Need regulatory approval and pilot tests to confirm inactivation of veligers.
Alternative 3: Chlorine Dioxide and Filters	Chlorine Dioxide, Mechanical Filters (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Chlorine dioxide dose: <1.4 mg/L (assumed); Dechlorination at Piedmont Valve Yard and between the SBA Terminal Tank and recharge ponds with sodium bisulfite	Need pilot tests for effectiveness against veligers. Need bench tests to determine demand/decay on District water.
Alternative 4: Filters and Ozone	Mechanical Filters, Ozone (located at Santa Clara Flow Meter Vault)	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ozone dose: <1 mg/L	

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
µm = micron
mg/L = milligrams per liter
mJ/cm^2 = millijoules per square centimeter
SBA = South Bay Aqueduct
UV = ultraviolet

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4.1.1 SBA System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and continuous UV irradiation to kill mussel eggs, veligers, and post-veligers.

Because the mussels to be excluded by filtration are 0.75 millimeter (mm) to 3 centimeters (cm), the ideal filter pore size is 120 to 150 µm absolute. The filter material should be weave wire, not wedge wire. Because some manufacturers of mechanical filters do not offer weave wire filter mesh at pore sizes greater than 60 µm, the design criteria for filter pore size has been broadened to 60 to 150 µm.

The assumed UV dose is 100 mJ/cm^2. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property by diverting flow in the SBA through several parallel lines, each with a filter followed by a UV reactor, before returning the stream to the SBA pipeline.

4.1.2 SBA System Full-Barrier Alternative 2: Mechanical Filters and Ferrate

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and addition of ferrate to kill mussel eggs, veligers, and post-veligers.

Ferrate would be added continuously at a dose of 1 mg/L. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property by diverting flow in the SBA through several filters operated in parallel, with ferrate addition upstream from the filters.

4.1.3 SBA System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and addition of chlorine dioxide to kill mussel eggs, veligers, and post-veligers.

It is assumed that chlorine dioxide would be fed continuously at a dose of 1.4 mg/L. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property by diverting flow in the SBA through several filters operated in parallel, with chlorine dioxide addition upstream from the filters. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body. Possible locations for diffusers to add sodium bisulfite include the Piedmont Valve Yard and between the SBA Terminal Tank and recharge ponds.

4.1.4 SBA System Full-Barrier Alternative 4: Mechanical Filters and Ozone

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and addition of ozone to kill mussel eggs, veligers, and post-veligers.

It is assumed that ozone would be fed continuously at a dose of 1 mg/L.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property by diverting flow in the SBA through several filters operated in parallel, followed by addition of ozone in a single header (using a sidestream assumed to be 10 percent of the total flow) before returning the stream to the SBA pipeline. If this alternative were selected, the SBA materials downstream of the Santa Clara Flow Meter Vault should be checked for compatibility with ozone. If the piping/lining materials are not compatible with ozone, replacement of the pipe with stainless steel or reinforced concrete pressure pipe would be necessary.

4.2 Full-Barrier Alternatives for the System Receiving San Luis Reservoir Water

Full-Barrier Alternatives for the District's raw water system receiving San Luis Reservoir (SLR) water (SLR System) are listed in Table 4-2 and described in the following subsections.

Table 4-2. Full-Barrier Alternatives for the San Luis Reservoir System

Full-Barrier Alternatives	Control Method for Protecting Vulnerable Equipment at the PPP	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Vulnerable Equipment at Coyote Pump Plant	Control Method for Protecting Reservoirs	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria	Data gaps
Alternative 1: Filters and UV	Supply pump cooling water and plant utility water from a point downstream of the filters and UV reactors	Mechanical Filters, UV Irradiation (located between pumps and regulating tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; UV dose: 100 mJ/cm^2	Required UV dose
Alternative 2: Ferrate and Filters	Ferrate	Mechanical Filters (located upstream of the PPP Regulating Tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ferrate dose: 1 mg/L	Ferrate is essentially a new treatment for the water industry. Need regulatory approval and pilot tests to confirm inactivation of veligers.
Alternative 3: Chlorine Dioxide and Filters	Chlorine Dioxide	Mechanical Filters (located upstream of the PPP Regulating Tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Chlorine dioxide dose: <1.4 mg/L (assumed); Dechlorination prior to the Hollister Biufurcation with sodium bisulfate	Need pilot tests for effectiveness against veligers. Need bench tests to determine demand/decay on District water.
Alternative 4: Filters and Ozone	Spot Treatments	Mechanical Filters (located between pumps and regulating tank), Ozone (located downstream of the PPP Regulating Tank)	Protected	Protected	Protected	Protected	Protected	Filter pore size range: 60 to 150 µm; Ozone dose: <1 mg/L	

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
µm = micron
mg/L = milligrams per liter
mJ/cm2 = millijoules per square centimeter
PPP = Pacheco Pump Plant
UV = ultraviolet

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4.2.1 SLR System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and continuous UV irradiation to kill mussel eggs, veligers, and post-veligers.

Because the mussels to be excluded by filtration are 0.75 mm to 3 cm, the ideal filter pore size is 120 to 150 µm absolute. The filter material should be weave wire, not wedge wire. Because some manufacturers of mechanical filters do not offer weave wire filter mesh at pore sizes greater than 60 µm, the design criteria for filter pore size has been broadened to 60 to 150 µm.

The assumed UV dose is 100 mJ/cm^2. If this alternative is selected, the dose should be further investigated.

It is assumed that this alternative would be implemented at the PPP between the pumps and the regulating tank, with diversion of flow through several parallel lines, each with a filter followed by a UV reactor. Because the control methods for this alternative would be implemented after the pumps at the PPP, spot treatments could be necessary to protect the utility, fire water, and pump cooling water systems at the PPP. Alternatively, water for these systems could be supplied from a point downstream of the control methods.

4.2.2 SLR System Full-Barrier Alternative 2: Mechanical Filters and Ferrate

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and addition of ferrate to kill mussel eggs, veligers, and post-veligers.

Ferrate would be added continuously at a dose of 1 mg/L. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented by delivering a ferrate solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir. The flow would be diverted through several filters operated in parallel and located between the pumps and the regulating tank.

4.2.3 SLR System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and addition of chlorine dioxide to kill mussel eggs, veligers, and post-veligers.

It is assumed that chlorine dioxide would be fed continuously at a dose of 1.4 mg/L. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented by delivering a chlorine dioxide solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir. The flow would be diverted through several filters operated in parallel and located between the pumps and the regulating tank. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body. A possible location for a diffuser to add sodium bisulfite is upstream of the Hollister Bifurcation.

4.2.4 SLR System Full-Barrier Alternative 4: Mechanical Filters and Ozone

This alternative consists of mechanical filters for protection from translocating adult and juvenile mussels and addition of ozone to kill mussel eggs, veligers, and post-veligers

Because the mussels to be excluded by filtration are 0.75 mm to 3 cm, the ideal filter pore size is 120 to 150 µm absolute. The filter material should be weave wire, not wedge wire. Because some manufacturers of mechanical filters do not offer weave wire filter mesh at pore sizes greater than 60 µm, the design criteria for filter pore size has been broadened to 60 to 150 µm.

It is assumed that ozone would be fed continuously at a dose of 1 mg/L.

It is assumed that this alternative would be implemented by diverting the flow through several filters operated in parallel between the pumps and the regulating tank at the PPP, with addition of ozone immediately downstream of the regulating tank using a sidestream assumed to be 10 percent of the total flow. If this alternative is selected, the pipeline and tunnel materials downstream of the regulating tank should be checked for compatibility with ozone. If the piping/lining materials are not compatible with ozone, replacement of the pipe with stainless steel or reinforced concrete pressure pipe would be necessary.

Because the control methods for this alternative are implemented after the pumps at the PPP, spot treatments would likely be necessary to protect the utility, fire water, and pump cooling water systems at the PPP.

4.3 Partial-Protection Alternatives for the SBA System

Partial-Protection Alternatives for the SBA System are listed in Table 4-3 and described in the following subsections.

Table 4-3. Partial-Protection Alternatives for the South Bay Aqueduct System

Partial-Protection Alternatives	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria
Alternative 1: pH Adjustment	Protected in areas with pH greater than 9.3 (caustic soda added at Santa Clara Flow Meter Vault; sulfuric acid added at Piedmont Valve Yard and between SBA Terminal Tank and recharge ponds)	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	pH for protection against mussels: Greater than 9.3; Required caustic soda concentration: 12 mg/L; pH for discharge to surface water: Less than 8.5; Required sulfuric acid concentration: 11 mg/L
Alternative 2a: Chlorine	No protection against translocating adults downstream of dechlorination (chlorine added at Santa Clara Flow Meter Vault; sodium bisulfite added at Piedmont Valve Yard and between SBA Terminal Tank and recharge ponds)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dose: 2.5 mg/L to achieve 0.5 mg/L residual after 2 hours
Alternative 2b: Chlorine Dioxide	No protection against translocating adults downstream of dechlorination (chlorine added at Santa Clara Flow Meter Vault; sodium bisulfite added at Piedmont Valve Yard and between SBA Terminal Tank and recharge ponds)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dioxide dose: 1.4 mg/L (assumed)
Alternative 3a: Continuous Potassium Feed	Potassium chloride (added at Santa Clara Flow Meter Vault)	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Protected	Required KCl concentration: 20 mg/L
Alternative 3b: Periodic Potassium Feed	Potassium chloride added at Santa Clara Flow Meter Vault annually to kill settled mussels and minimize impacts	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Potassium chloride added annually to kill settled mussels and minimize impacts	Required KCl concentration: 20 mg/L Duration of addition period: 52 days
Alternative 4: Spot Treatments for Vulnerable Equipment	None	None	None	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	To be developed if selected

Notes:

"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
KCl = potassium chloride
mg/L = milligrams per liter
SBA = South Bay Aqueduct

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4.3.1 SBA System Partial-Protection Alternative 1: pH Adjustment

This alternative consists of continuous pH adjustment to prevent settlement/survival of mussels in the protected segment of the raw water system.

The desired pH for protection against mussels is 9.3 or greater. If this alternative is selected, the effectiveness of high pH for mussel control and the potential for resulting precipitation should be further investigated with pilot testing.

It is assumed that sodium hydroxide (caustic soda) would be preferred over calcium oxide (lime) for pH adjustment. Based on typical SBA water quality conditions, a dose of approximately 70 pounds of caustic soda per million gallons of water (for a concentration of 8.4 mg/L) is required to raise the pH to 9.4. The quantity of caustic soda needed will fluctuate with changes in pH and alkalinity of SBA water.

Although high pH is desired to protect the raw water system, the pH would have to be less than 8.5 before coagulation at treatment plants or discharge to a local reservoir. It is assumed that sulfuric acid would be used to lower the pH to approximately 8.2. A dose of approximately 80 pounds of sulfuric acid per million gallons of water (for a concentration of 9.6 mg/L) is required to lower the pH from 9.4 to 8.2.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property with a diffuser in the SBA to add caustic soda. Additional diffusers to add sulfuric acid would be added at locations where the pH should be lowered.

4.3.2 SBA System Partial-Protection Alternative 2a: Chlorine

This alternative consists of chlorine addition to prevent settlement/survival of mussels in the protected segment of the raw water system and kill mussel eggs, veligers, and post-veligers. Chlorine was not recommended as a Full-Barrier Alternative because its use for mussel control in the raw water transmission system would almost certainly result in a violation of the THM standard in water supplied to the District's customers. It is included in the evaluation of Partial-Protection Alternatives because this is expected to be a short-term solution until the selected Full-Barrier Alternative is operational.

Chlorine would be fed at a dose of 2.5 mg/L to maintain a residual of 0.5 mg/L for a duration of two hours or more.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add chlorine. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body. Possible locations for diffusers to add sodium bisulfite include the Piedmont Valve Yard and between the SBA Terminal Tank and recharge ponds.

4.3.3 SBA System Partial-Protection Alternative 2b: Chlorine Dioxide

This alternative consists of chlorine dioxide addition to prevent settlement/survival of mussels in the protected segment of the raw water system and kill mussel eggs, veligers, and post-veligers.

It is assumed that chlorine dioxide would be fed continuously at a dose of 1.4 mg/L. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add chlorine dioxide. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body. Possible locations for diffusers to add sodium bisulfite include the Piedmont Valve Yard and between the SBA Terminal Tank and recharge ponds.

4.3.4 SBA System Partial-Protection Alternative 3a: Continuous Potassium Feed

This alternative consists of potassium chloride addition to prevent settlement of mussels in the raw water system. Based on previous studies, it is assumed that the treatment would require a concentration of 20 mg/L, but because this is proposed as a continuous feed system, a lower concentration may be possible. It is not guaranteed that potassium would kill 100 percent of larvae, and those that survive could be carried through the system to surface water discharges where the potassium concentration may be tolerable.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add potassium chloride.

4.3.5 SBA System Partial-Protection Alternative 3b: Periodic Potassium Feed

This alternative consists of an annual potassium chloride addition event to kill settled mussels in the raw water system. Based on previous studies, it is anticipated that the treatment would require a concentration of 20 mg/L in the system for 52 days to achieve close to 100 percent mortality in the settled mussel populations. Because this alternative will not be operated continuously, it is not expected to protect reservoirs and other water bodies that receive water from the raw water system.

It is assumed that this alternative would be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add potassium chloride.

4.3.6 SBA System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment

The objective of this alternative is to protect specifically-identified vulnerable equipment (e.g., systems for pump cooling water or fire suppression) and maintain successful operation of that equipment. Mechanical filters or cartridge filters could be installed on the utility water lines at Vasona Pump Plant to prevent shells and ready-to-settle mussels from entering the pump cooling water and fire protection systems. Alternatively, a strainer could be used, if the goal was simply to prevent shells from entering the system. If settled mussels are discovered in the utility water systems, chemicals, such as potassium or chlorine, or hot water could periodically be added to the utility water lines to eradicate them.

4.4 Partial-Protection Alternatives for the SLR System

Partial-Protection Alternatives for the SLR System are listed in Table 4-4 and described in the following subsections.

Table 4-4. Partial-Protection Alternatives for the San Luis Reservoir System

Partial-Protection Alternatives	Control Method for Protecting Vulnerable Equipment at the PPP	Control Method for Protecting Raw Water Conveyance System	Control Method for Protecting Vulnerable Equipment at Coyote Pump Plant	Control Method for Protecting Calero Reservoir	Control Method for Protecting Recharge Ponds	Control Method for Protecting Creeks	Control Method for Protecting Vulnerable Equipment at Vasona Pump Plant	Basic Design Criteria
Alternative 1: pH Adjustment	pH Adjustment	Protected in areas with pH greater than 9.3; pH neutralization prior to the Hollister Bifurcation	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	No protection downstream of second pH adjustment	pH for protection against mussels: Greater than 9.3; Required caustic soda concentration: 12 mg/L; pH for discharge to surface water: Less than 8.5; Required sulfuric acid concentration: 11 mg/L
Alternative 2a: Chlorine	Chlorine	No protection against translocating adults downstream of dechlorination with sodium bisulfite (prior to the Hollister Biufurcation)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dose: 2.5 mg/L to achieve 0.5 mg/L residual after 2 hours
Alternative 2b: Chlorine Dioxide	Chlorine Dioxide	No protection against translocating adults downstream of dechlorination with sodium bisulfite (prior to the Hollister Biufurcation)	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	No protection against translocating adults	Chlorine dose: 1.4 mg/L (assumed)
Alternative 3a: Continuous Potassium Feed	Potassium chloride	Protected	Protected	Only protected if potassium concentrations remain high enough	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Protected	Required KCl concentration: 20 mg/L
Alternative 3b: Periodic Potassium Feed	Potassium chloride added annually to kill settled mussels and minimize impacts	Potassium chloride added annually to kill settled mussels and minimize impacts	Potassium chloride added annually to kill settled mussels and minimize impacts	None	Pending regulatory and operational constraints, mussel populations in recharge ponds could potentially be controlled with system water containing potassium	Only protected if potassium concentrations remain high enough and discharge with potassium is permitted	Potassium chloride added annually to kill settled mussels and minimize impacts	Required KCl concentration: 20 mg/L Duration of addition period: 52 days
Alternative 4: Spot Treatments for Vulnerable Equipment	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	None	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	None	None	None	Mechanical filters, cartridge filters, or strainers on the pump cooling water lines and the fire system. Periodic addition of chemicals or hot water to kill settled mussels may be necessary.	Other design criteria to be developed if selected

Notes:
"Protected" indicates that control methods applied upstream as part of this alternative also provide protection for the portion of the system in question.

Key:
KCl = potassium chloride
mg/L = milligrams per liter
PPP = Pacheco Pump Plant

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4.4.1 SLR System Partial-Protection Alternative 1: pH Adjustment

This proactive alternative consists of continuous pH adjustment to prevent settlement/survival of mussels in the protected segment of the raw water system.

The desired pH for protection against mussels is 9.3 or greater. If this alternative is selected, the effectiveness of mussel control with high pH should be further investigated with pilot testing.

It is assumed that sodium hydroxide (caustic soda) would be preferred over calcium oxide (lime) for pH adjustment. Based on typical San Luis Reservoir water quality conditions, a dose of approximately 98 pounds of caustic soda per million gallons of water (for a concentration of 11.7 mg/L) is required to raise the pH to 9.4. The quantity of caustic soda needed will fluctuate with changes in pH and alkalinity of San Luis Reservoir water.

Although high pH is desired to protect the raw water system, the pH would have to be less than 8.5 before coagulation at treatment plants or discharge to a local reservoir. It is assumed that sulfuric acid would be used to lower the pH to approximately 8.2. A dose of approximately 87 pounds of sulfuric acid per million gallons of water (for a concentration of 10.4 mg/L) is required to lower the pH from 9.4 to 8.2.

It is assumed that this alternative would be implemented by delivering a caustic soda solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir. Diffusers to add sulfuric acid would be added at locations where the pH should be lowered.

4.4.2 SLR System Partial-Protection Alternative 2a: Chlorine

This proactive alternative consists of chlorine addition to prevent settlement/survival of mussels in the protected segment of the raw water system and kill mussel eggs, veligers, and post-veligers. Chlorine was not recommended as a Full-Barrier Alternative because its use for mussel control in the raw water transmission system would almost certainly result in a violation of the THM standard in water supplied to the District's customers. It is included in the evaluation of Partial-Protection Alternatives because this is expected to be a short-term solution until the selected Full-Barrier Alternative is operational.

Chlorine would be fed at a dose of 2.5 mg/L to maintain a residual of 0.5 mg/L for a duration of two hours or more.

It is assumed that this alternative would be implemented by delivering a sodium hypochlorite solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body. A possible location for a diffuser to add sodium bisulfite is upstream of the Hollister Bifurcation.

4.4.3 SLR System Partial-Protection Alternative 2b: Chlorine Dioxide

This alternative consists of chlorine dioxide addition to prevent settlement/survival of mussels in the protected segment of the raw water system and kill mussel eggs, veligers, and post-veligers.

It is assumed that chlorine dioxide would be fed continuously at a dose of 1.4 mg/L. If this alternative is selected, the dose should be further investigated with pilot testing.

It is assumed that this alternative would be implemented by delivering a chlorine dioxide solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body. A possible location for a diffuser to add sodium bisulfite is upstream of the Hollister Bifurcation.

4.4.4 SLR System Partial-Protection Alternative 3a: Continuous Potassium Feed

This alternative consists of continuous potassium chloride addition to prevent settlement of mussels in the raw water system. Based on previous studies, it is assumed that the treatment would require a concentration of 20 mg/L, but because this is proposed as a continuous feed system, a lower concentration may be possible. It is not guaranteed that potassium would kill 100 percent of larvae, and those that survive could be carried through the system to surface water discharges where the potassium concentration may be tolerable.

It is assumed that this alternative would be implemented by delivering a potassium chloride solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir.

4.4.5 SLR System Partial-Protection Alternative 3b: Periodic Potassium Feed

This alternative consists of an annual potassium chloride addition event to kill settled mussels in the raw water system. Based on previous studies, it is anticipated that the treatment would require a concentration of 20 mg/L in the system for 52 days to achieve close to 100 percent mortality in the settled mussel populations. Because this alternative will not be operated continuously, it is not expected to protect reservoirs and other water bodies that receive water from the raw water system.

It is assumed that this alternative would be implemented by delivering a potassium chloride solution through piping in the PPP Surge Shaft and Pacheco Tunnel Reach 1 with addition immediately downstream of the upper intake at San Luis Reservoir.

4.4.6 SLR System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment

The objective of this alternative is to protect specifically-identified vulnerable equipment (e.g., systems for pump cooling water or fire suppression) and maintain successful operation of that equipment. Mechanical filters or cartridge filters could be installed on the utility water lines at Pacheco Pump Plant and Coyote Pump Plant to prevent shells and ready-to-settle mussels from entering the pump cooling water and fire protection systems. Alternatively, a strainer could be used, if the goal was simply to prevent shells from entering the system. If settled mussels are discovered in the utility water systems, chemicals, such as potassium or chlorine, or hot water could periodically be added to the utility water lines to eradicate them.

4.5 Reactive Mitigation Alternatives

Reactive Mitigation Alternatives are listed in Table 4-5 and described in the following subsections.

Table 4-5. Reactive Mitigation Alternatives

Mitigation Alternatives	Reactive Control Method for Settled Mussels	Basic Design Criteria
Alternative 1	pH Adjustment (Periodic treatment in conveyance system for 30 to 45 days)	pH for protection against mussels: Greater than 9.3 Required caustic soda concentration: 8 to 12 mg/L pH for discharge to surface water: Less than 8.5 Required sulfuric acid concentration: 9 to 11 mg/L
Alternative 2	Chlorine (Periodic treatment in conveyance system for 10 to 20 days)	0.5 mg/L residual chlorine at all targeted locations
Alternative 3	Potassium Chloride (Periodic treatment for 52 days)	Required concentration: 20 mg/L
Alternative 4	Bacteria-Based Molluscicide	Determine dose when more product information is available.

Key:
mg/L = milligrams per liter

4.5.1 Reactive Mitigation Alternative 1: pH Adjustment

This reactive mitigation alternative consists of periodic pH adjustment to kill settled mussels in the raw water system. Treatment with high pH would likely require a duration of one month or more to significantly impact the settled mussel populations.

The desired pH to kill settled mussels in the raw water system is 9.3 or greater. It is assumed that sodium hydroxide (caustic soda) would be preferred over calcium oxide (lime) for raising the pH. The pH would have to be less than 8.5 before coagulation at treatment plants or discharge to a local reservoir. It is assumed that sulfuric acid would be used to lower the pH to approximately 8.2.

This alternative could be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add caustic soda or at the PPP with caustic soda addition through the surge tower. Additional diffusers to add sulfuric acid could be added at locations where the pH should be lowered.

Based on typical District raw water conditions, 8 to 12 mg/L of caustic soda would be required to raise the pH to 9.4. The quantity of caustic soda needed will fluctuate with changes in pH and alkalinity of the source water. Approximately 9 to 11 mg/L of sulfuric acid would be required to lower the pH from 9.4 to 8.2.

4.5.2 Reactive Mitigation Alternative 2: Chlorine

This alternative consists of periodic chlorine addition to kill settled mussels in the raw water system. Treatment with 0.5 mg/L chlorine in the targeted areas for 10 to 20 days would significantly impact the settled mussel populations.

This alternative could be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add sodium hypochlorite or at the PPP with sodium hypochlorite addition through the surge tower. Dechlorination, with sodium bisulfite or equivalent, would be necessary prior to discharging to a surface water body (if surface water discharges cannot be avoided during the treatment period).

4.5.3 Reactive Mitigation Alternative 3: Potassium Chloride

This reactive mitigation alternative consists of potassium chloride addition to kill settled mussels in the raw water system. Based on previous studies, it is anticipated that the treatment would require a concentration of 20 mg/L in the system for 52 days to achieve close to 100 percent mortality in the settled mussel populations. This alternative is similar to Partial-Protection Alternative 3b, Periodic Potassium Feed.

This alternative could be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add potassium chloride or at the PPP with potassium chloride addition through the surge tower. Potassium chloride could also be added directly to a reservoir for eradication purposes if regulatory approval was granted.

4.5.4 Reactive Mitigation Alternative 4: Bacteria-Based Molluscicide

This reactive mitigation alternative consists of Zequanox^{TM} addition to kill settled mussels in the raw water system or reservoirs. The timeframe for availability of Zequanox^{TM} as an approved product is uncertain, however.

Information about typical doses and contact time for Zequanox^{TM} are still being developed by the manufacturer. Results from Reclamation's demonstration tests at Davis Dam indicate that greater than 80 percent mortality can be achieved after 15 days with a dose of 100 ppm.

This alternative could be implemented at the Santa Clara Flow Meter Vault property with one diffuser in the SBA to add Zequanox^{TM} or at the PPP with Zequanox^{TM} addition through the surge tower. Alternatively, Zequanox^{TM} could be added directly into San Luis Reservoir or a local reservoir.

4.6 Order-of-Magnitude Cost Estimates for Full-Barrier and Partial-Protection Alternatives

Order-of-magnitude cost estimates, including capital and operations and maintenance (O&M) costs, were developed for each of the Full-Barrier and Partial-Protection Alternatives on each of the two imported raw water systems. **These approximate costs were developed without conceptual designs and are intended for relative comparison, not for budgeting.**

Cost estimates were not developed for Reactive Mitigation Alternatives because the costs will depend on the circumstances of the application.

4.6.1 Order-of-Magnitude Capital Costs for Full-Barrier Alternatives

Table 4-6 presents a comparison of order-of-magnitude capital costs for Full-Barrier Alternatives, estimated separately for the SBA and SLR systems.

Equipment and installation costs were developed with assumed maximum flow rates of 185 cfs (120 million gallons per day (mgd)) for the SBA System and 480 cfs (310 mgd) for the SLR System.

Capital costs for mechanical filtration were based on a preliminary cost estimate for Hydac filters. Capital costs for mechanical filtration also include backwash water and solids treatment and disposal. Two lamella plate clarifiers and two storage basins (12,992 cubic feet of storage volume each) are included as part of the solids handling facilities for the SBA System. Three lamella plate clarifiers and two screw presses are included as part of the solids handling facilities for the SLR System.

Capital costs for the UV system are based on budgetary quotes provided by Calgon Carbon Corporation for the SBA and SLR systems, with an assumed dose of 100 mJ/cm^2 and UVT of 80 percent. The SBA System would include four trains, each with three 48-inch diameter, medium pressure lamp UV reactors in series. The SLR System would include nine trains, each with three 48-inch diameter, medium pressure lamp UV reactors in series.

Capital costs for ferrate include a Ferrator system, storage, piping, and diffusers, and were scaled from a preliminary cost estimate provided by FTT for a similar project. The quoted equipment cost was adjusted by a factor of 1.5 to cover installation costs.

Capital costs for chlorine dioxide are based on similar facilities and include chemical storage, piping, and diffusers for addition at one location per system.

Capital costs for ozone are based on similar facilities and include ozone generation equipment. The estimated equipment cost was adjusted by a factor of 5 to cover installation costs.

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Table 4-6. Comparison of Order-of-Magnitude Capital Costs for Full-Barrier Alternatives

Alternatives	Cost Description 1	Capital Costs 1	Cost Description 2	Capital Costs 2	Cost Description 3	Capital Costs 3	Total Capital Costs
SBA System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation	7 Stainless Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$3,413,000	UV System	$16,000,000	Solids Handling Facilities and Office Trailer	$1,278,000	$20,700,000
SBA System Full-Barrier Alternative 2: Mechanical Filters and Ferrate	7 Stainless Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$4,134,000	Ferrate System	$5,156,000	Solids Handling Facilities and Office Trailer	$1,278,000	$10,600,000
SBA System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide	7 Stainless Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$4,134,000	Chlorine Dioxide System	$2,901,000	Solids Handling Facilities and Office Trailer	$1,278,000	$8,300,000
SBA System Full-Barrier Alternative 4: Mechanical Filters and Ozone	7 Stainless Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$3,413,000	Ozone System	$26,000,000	Solids Handling Facilities and Office Trailer	$1,278,000	$30,700,000
SLR System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation	18 Carbon Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$8,945,000	UV System	$37,000,000	Solids Handling Facilities	$3,685,000	$49,600,000
SLR System Full-Barrier Alternative 2: Mechanical Filters and Ferrate	18 Stainless Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$10,798,000	Ferrate System	$13,327,000	Solids Handling Facilities	$3,685,000	$27,800,000
SLR System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide	18 Stainless Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$10,798,000	Chlorine Dioxide System	$6,058,000	Solids Handling Facilities	$3,685,000	$20,500,000
SLR System Full-Barrier Alternative 4: Mechanical Filters and Ozone	18 Carbon Steel Mechanical Filters (60 µm pore size, 14,000-gpm each) plus related piping, valves, and vault	$8,945,000	Ozone System	$69,000,000	Solids Handling Facilities	$3,685,000	$81,600,000

Notes

These costs are approximate and were developed without detailed designs. These costs are intended for relative comparison, not for budgeting.

key:
µm = micron
gpm = gallons per minute
SBA = South Bay Aqueduct
SLR = San Luis Reservoir
UV = ultraviolet

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4.6.2 Order-of-Magnitude O&M Costs for Full-Barrier Alternatives

Table 4-7 presents a comparison of order-of-magnitude O&M costs for Full-Barrier Alternatives, including a 25-year present worth calculation with an assumed interest rate of 5 percent.

SBA System O&M costs assume approximately 61,000 acre-feet per year (AF/year) (based on 85 cfs, 55 mgd). SLR System O&M costs assume approximately 161,000 AF/year (based on 225 cfs, 145 mgd).

Labor costs are estimated for one full-time equivalent (FTE) for the SBA System and 2 FTEs for the SLR System. Maintenance costs are estimated at 2.5% of the capital costs.

No additional pumping costs are assumed for either the SBA or SLR systems.

Power costs for Alternative 1, Filters and UV, are based on estimates provided by the Calgon Carbon Corporation for the SBA and SLR systems, with an assumed dose of 100 mJ/cm^2 and UVT of 80 percent. Energy costs are assumed to be $0.11 per kilowatt-hour.

Chemical costs for Alternative 2, Filters and Ferrate, are based on a preliminary cost estimate provided by FTT for a similar project, at approximately $43 per million gallons of treated water for a ferrate dose of 1 mg/L.

Chemical costs for Alternative 3, Filters and Chlorine Dioxide, are primarily based on a proposal prepared by IDI-DuPont Water Technologies. The proposal is included as an appendix to the Conceptual Design Report (MWH, 2011).

O&M costs for Alternative 4, Filters and Ozone, are based on a preliminary cost estimate for a similar project, at approximately $11 per million gallons of treated water for an ozone dose of 1.0 mg/L.

O&M costs for transportation and disposal of solids from the SBA System are based on transportation of wet solids (i.e., stored clarifier underflow water and sediment). The estimate for this item is based on an average of 5 truckloads per day and a quote from Philips Service Corporation of $600 per load. This cost does not include any disposal fees once the material is delivered to the destination treatment plant. See the Conceptual Design Report (MWH, 2011) for more details.

O&M costs for transportation and disposal of solids (i.e., cake from the screw press) from the SLR System are based on current costs (approximately $29 per ton) to dispose of similar material from Penitencia Water Treatment Plant at Newby Island Sanitary Landfill in Milpitas, California and the cost of fuel for each round trip from Pacheco Pump Plant to Newby Island Sanitary Landfill. The cost of two trucks is included in the OPCC, and the driver is included in the O&M costs as one FTE. See the Conceptual Design Report (MWH, 2011) for more details.

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Table 4-7. Comparison of Order-of-Magnitude Operations and Maintenance Costs for Full-Barrier Alternatives

Alternatives	Cost Description 1	Annual Costs 1	Cost Description 2	Annual Costs 2	Cost Description 3	Annual Costs 3	Annual O&M Subtotal	25-Year Present Worth Life Cycle Cost (R=5%)
SBA System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$617,500	Energy Costs for UV Radiation (100 mJ/cm^2 with 80% UVT)	$1,293,000	Transportation and disposal of solids	$1,005,000	$2,900,000	$40,900,000
SBA System Full-Barrier Alternative 2: Mechanical Filters and Ferrate	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$365,000	Chemical costs for Ferrate (1 mg/L)	$896,000	Transportation and disposal of solids	$1,005,000	$2,300,000	$32,400,000
SBA System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$307,500	Chemical Costs for Chlorine Dioxide (1.4 mg/L)	$921,000	Transportation and disposal of solids	$1,005,000	$2,200,000	$31,000,000
SBA System Full-Barrier Alternative 4: Mechanical Filters and Ozone	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$867,000	Chemical and Energy Costs for Ozone (1 mg/L)	$228,000	Transportation and disposal of solids	$1,005,000	$2,100,000	$29,600,000
SLR System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation	Labor (2 FTE) and Maintenance (2.5% of capital costs)	$1,440,000	Energy Costs for UV Radiation (100 mJ/cm^2 with 80% UVT)	$2,912,000	Transportation and disposal of solids	$52,000	$4,300,000	$62,000,000
SLR System Full-Barrier Alternative 2: Mechanical Filters and Ferrate	Labor (2 FTE) and Maintenance (2.5% of capital costs)	$895,000	Chemical costs for Ferrate (1 mg/L)	$2,361,000	Transportation and disposal of solids	$52,000	$3,300,000	$46,500,000
SLR System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide	Labor (2 FTE) and Maintenance (2.5% of capital costs)	$712,500	Chemical Costs for Chlorine Dioxide (1.4 mg/L)	$2,422,000	Transportation and disposal of solids	$52,000	$3,200,000	$45,100,000
SLR System Full-Barrier Alternative 4: Mechanical Filters and Ozone	Labor (2 FTE) and Maintenance (2.5% of capital costs)	$2,240,000	Chemical and Energy Costs for Ozone (1 mg/L)	$586,000	Transportation and disposal of solids	$52,000	$2,800,000	$40,900,000

Notes

These costs are approximate and were developed without detailed designs. These costs are intended for relative comparison, not for budgeting.

SBA System O&M costs assume approximately 61,000 AF/year (based on 85 cfs). SLR System O&M costs assume approximately 161,000 AF/year (based on 225 cfs).

SBA System O&M costs assume 677 AF/year of backwash water and 33,500 tons/yr of wet solids. SLR System O&M costs assume 1,355 AF/year of backwash water and 944 tons per year of cake solids.

Net interest rate, R, is assumed to be 5percent.

Key:
mg/L = milligrams per liter
mJ/cm^2 = millijoules per square centimeter
O&M = operations and maintenance
SBA = South Bay Aqueduct
SLR = San Luis Reservoir
UVT = UV transmittance

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4.6.3 Order-of-Magnitude Total Project Costs for Full-Barrier Alternatives

Table 4-8 presents the order-of-magnitude 25-year present worth total project costs for Full-Barrier Alternatives, estimated separately for the SBA and SLR systems.

The least expensive option considered for each system is Alternative 3, followed by Alternative 2. Alternatives 1 and 4 are the most expensive options.

Table 4-8. Comparison of Order-of-Magnitude Total Project Costs for Full-Barrier Alternatives

Alternatives	Total Capital Costs	25-Year Present Worth Life Cycle Cost (R=5%)	Total Project Cost (25-Year Present Worth)
SBA System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation	$20,700,000	$40,900,000	$62,000,000
SBA System Full-Barrier Alternative 2: Mechanical Filters and Ferrate	$10,600,000	$32,400,000	$43,000,000
SBA System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide	$8,300,000	$31,000,000	$39,000,000
SBA System Full-Barrier Alternative 4: Mechanical Filters and Ozone	$30,700,000	$29,600,000	$60,000,000
SLR System Full-Barrier Alternative 1: Mechanical Filters and UV Irradiation	$49,600,000	$62,000,000	$112,000,000
SLR System Full-Barrier Alternative 2: Mechanical Filters and Ferrate	$27,800,000	$46,500,000	$74,000,000
SLR System Full-Barrier Alternative 3: Mechanical Filters and Chlorine Dioxide	$20,500,000	$45,100,000	$66,000,000
SLR System Full-Barrier Alternative 4: Mechanical Filters and Ozone	$81,600,000	$40,900,000	$123,000,000

Notes

These costs are approximate and were developed without detailed designs. These costs are intended for relative comparison, not for budgeting.

Net interest rate, R, is assumed to be 5 percent.

Key:
SBA = South Bay Aqueduct
SLR = San Luis Reservoir
UV = ultraviolet

4.6.4 Order-of-Magnitude Capital Costs for Partial-Protection Alternatives

Table 4-9 presents a comparison of order-of-magnitude capital costs for Partial-Protection Alternatives, estimated separately for the SBA and SLR systems.

Equipment and installation costs were developed with assumed maximum flow rates of 185 cfs (120 mgd) for the SBA System and 480 cfs (310 mgd) for the SLR System.

Capital costs for pH adjustment include storage, piping, and in-line mixing for addition of caustic soda at one location per system and storage, piping, and diffusers for addition of sulfuric acid at two SBA System locations and one SLR System location.

Capital costs for chlorine and chlorine dioxide include storage, piping, and in-line mixing for addition at one location per system and storage, piping, and diffusers for dechlorination at two SBA System locations and one SLR System location.

Capital costs for potassium chloride include storage, piping, and in-line mixing for addition at one location per system.

For the purpose of comparing costs and evaluating alternatives, the spot treatment alternatives were assumed to include mechanical filters on pump cooling systems and utility water lines and periodic treatment with chemicals or hot water.

Costs for piping in PPP Surge Shaft and Pacheco Tunnel Reach 1 were not included for Partial-Protection Alternatives, as the costs are already included for Full-Barrier Alternatives.

Table 4-9. Comparison of Order-of-Magnitude Capital Costs for Partial-Protection Alternatives

Alternatives	Cost Description	Capital Costs
SBA System Partial-Protection Alternative 1: pH Adjustment	Storage, piping, and in-line mixers for caustic soda and sulfuric acid	$1,739,000
SBA System Partial-Protection Alternative 2a: Chlorine	Storage, piping, and in-line mixers for chlorine and dechlorination facilities	$1,538,000
SBA System Partial-Protection Alternative 2b: Chlorine Dioxide	Storage, piping, and in-line mixers for chlorine dioxide and dechlorination facilities	$2,131,000
SBA System Partial-Protection Alternative 3a: Continuous Potassium Feed	Storage, piping, and in-line mixer for potassium chloride addition for entire flow range	$2,036,000
SBA System Partial-Protection Alternative 3b: Periodic Potassium Feed	Storage, feed equipment, and piping for potassium chloride addition when imported water deliveries are typically low	$1,380,000
SBA System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment	Mechanical filters, along with storage and connections for hot water or chemicals, for pumps cooling water, utility water, and fire system water at Vasona Pump Plant	$300,000
SLR System Partial-Protection Alternative 1: pH Adjustment	Storage, feed equipment, and piping for caustic soda and sulfuric acid	$3,762,000
SLR System Partial-Protection Alternative 2a: Chlorine	Chemical storage and chemical building, and controls for chlorine and dechlorination facilities	$1,681,000
SLR System Partial-Protection Alternative 2b: Chlorine Dioxide	Chemical storage and chemical building, ClO2 generation, and controls for chlorine dioxide and dechlorination facilities	$2,298,000
SLR System Partial-Protection Alternative 3a: Continuous Potassium Feed	Storage, piping, and in-line mixer for potassium chloride addition for entire flow range	$3,513,000
SLR System Partial-Protection Alternative 3b: Periodic Potassium Feed	Storage, feed equipment, and piping for potassium chloride addition when imported water deliveries are typically low	$1,568,000
SLR System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment	Mechanical filters, along with storage and connections for hot water or chemicals, for pumps cooling water, utility water, and fire system water at Pacheco and Coyote pump plants	$600,000

Notes

These costs are approximate and were developed without detailed designs. These costs are intended for relative comparison, not for budgeting.

Key;
SBA = South Bay Aqueduct
SLR = San Luis Reservoir

4.6.5 Order-of-Magnitude O&M Costs for Partial-Protection Alternatives

Table 4-10 presents a comparison of order-of-magnitude O&M costs for Partial-Protection Alternatives, including a 5-year present worth calculation with an assumed interest rate of 5 percent.

SBA System O&M costs assume approximately 61,000 AF/year (based on 85 cfs, 55 mgd). SLR System O&M costs assume approximately 161,000 AF/year (based on 225 cfs, 145 mgd).

Labor costs are estimated for one FTE for the SBA System and 2 FTEs for the SLR System. Maintenance costs are estimated at 2.5% of the capital costs.

Assumed chemical costs are listed below:

- $410 per dry ton of caustic soda (50 percent membrane-grade sodium hydroxide, delivered to Santa Clara County).
- $220 per wet ton of sulfuric acid (93 percent NSF-grade, delivered to Santa Clara County).
- $0.679 per pound of pure chlorine equivalent.
- Chlorine dioxide chemical precursors included 31 percent solution of sodium chlorite at $0.61 per pound, 12.5 percent solution of sodium hypochlorite at $0.105 per pound, and 15 percent solution of hydrochloric acid at $0.106 per pound.
- $125 per ton of potassium chloride.

Dechlorination chemical costs are not included in the O&M cost estimate.

Table 4-10. Comparison of Order-of-Magnitude Operations and Maintenance Costs for Partial-Protection Alternatives

Protection Strategy Alternatives	Cost Description 1	Annual Costs 1	Cost Description 2	Annual Costs 2	Annual O&M Costs	5-Year Present Worth Life Cycle Cost (R=5%)
SBA System Partial-Protection Alternative 1: pH Adjustment	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$143,475	pH adjustment with caustic soda at 7.8 mg/L and sulfuric acid at 9.9 mg/L	$450,000	$572,900	$2,569,000
SBA System Partial-Protection Alternative 2a: Chlorine	Labor (0.5 FTE) and Maintenance (2.5% of capital costs)	$88,450	Chemical Costs for Chlorine (2.5 mg/L feed)	$284,000	$372,450	$1,613,000
SBA System Partial-Protection Alternative 2b: Chlorine Dioxide	Labor (0.5 FTE) and Maintenance (2.5% of capital costs)	$103,275	Chemical Costs for Chlorine Dioxide (1.4 mg/L feed)	$830,000	$933,275	$4,041,000
SBA System Partial-Protection Alternative 3a: Continuous Potassium Feed	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$196,625	Potassium chloride (20 mg/L)	$1,836,000	$1,986,900	$8,602,000
SBA System Partial-Protection Alternative 3b: Periodic Potassium Feed	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$134,500	Potassium chloride (20 mg/L) for 52 days per year	$212,000	$346,500	$1,500,000
SBA System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment	Labor (0.5 FTE) and Maintenance (2.5% of capital costs)	$57,500	Additional pumping costs and periodic chemical addition (negligible)	$0	$57,500	$249,000
SLR System Partial-Protection Alternative 1: pH Adjustment	Labor (2 FTE) and Maintenance (2.5% of capital costs)	$294,050	pH adjustment with caustic soda at 11.2 mg/L and sulfuric acid at 10.7 mg/L	$1,500,000	$1,739,525	$7,767,000
SLR System Partial-Protection Alternative 2a: Chlorine	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$142,025	Chemical Costs for Chlorine (2.5 mg/L feed)	$750,000	$892,025	$3,862,000
SLR System Partial-Protection Alternative 2b: Chlorine Dioxide	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$157,450	Chemical Costs for Chlorine Dioxide (1.4 mg/L feed)	$2,200,000	$2,357,450	$10,207,000
SLR System Partial-Protection Alternative 3a: Continuous Potassium Feed	Labor (2 FTE) and Maintenance (2.5% of capital costs)	$409,025	Potassium chloride (20 mg/L)	$4,840,000	$5,127,825	$22,201,000
SLR System Partial-Protection Alternative 3b: Periodic Potassium Feed	Labor (1 FTE) and Maintenance (2.5% of capital costs)	$139,200	Potassium chloride (20 mg/L) for 52 days per year	$380,000	$519,200	$2,248,000
SLR System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment	Labor (0.5 FTE) and Maintenance (2.5% of capital costs)	$65,000	Additional pumping costs and periodic chemical addition (negligible)	$0	$65,000	$281,000

Notes
These costs are approximate and were developed without detailed designs. These costs are intended for relative comparison, not for budgeting.
SBA O&M costs assume approximately 61,000 AF/year (based on 85 cfs). SLR O&M costs assume approximately 161,000 AF/year (based on 225 cfs).
Net interest rate, R, is assumed to be 5 percent.

Key:
mg/L = milligrams per liter
O&M = operations and maintenance
SBA = South Bay Aqueduct
SLR = San Luis Reservoir

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4.6.6 Order-of-Magnitude Total Project Costs for Partial-Protection Alternatives

Table 4-11 presents the 5-year present worth total project costs for Partial-Protection Alternatives, estimated separately for the SBA and SLR systems.

The least expensive option that was considered for each system is Alternative 4. Alternatives 3b, 2a, 1, 2b, and 3a were progressively more expensive, in that order.

Table 4-11. Comparison of Order-of-Magnitude Total Project Costs for Partial-Protection Alternatives

Alternatives	Total Capital Costs	5-Year Present Worth Life Cycle Cost (R=5%)	Total Project Cost (5-Year Present Worth)
SBA System Partial-Protection Alternative 1: pH Adjustment	$1,739,000	$2,569,000	$4,300,000
SBA System Partial-Protection Alternative 2a: Chlorine	$1,538,000	$1,613,000	$3,200,000
SBA System Partial-Protection Alternative 2b: Chlorine Dioxide	$2,131,000	$4,041,000	$6,200,000
SBA System Partial-Protection Alternative 3a: Continuous Potassium Feed	$2,036,000	$8,602,000	$10,600,000
SBA System Partial-Protection Alternative 3b: Periodic Potassium Feed	$1,380,000	$1,500,000	$2,900,000
SBA System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment	$300,000	$249,000	$500,000
SLR System Partial-Protection Alternative 1: pH Adjustment	$3,762,000	$7,767,000	$12,000,000
SLR System Partial-Protection Alternative 2a: Chlorine	$1,681,000	$3,862,000	$5,500,000
SLR System Partial-Protection Alternative 2b: Chlorine Dioxide	$2,298,000	$10,207,000	$12,500,000
SLR System Partial-Protection Alternative 3a: Continuous Potassium Feed	$3,513,000	$22,201,000	$25,700,000
SLR System Partial-Protection Alternative 3b: Periodic Potassium Feed	$1,568,000	$2,248,000	$3,800,000
SLR System Partial-Protection Alternative 4: Spot Treatments for Vulnerable Equipment	$600,000	$281,000	$900,000

Notes

These costs are approximate and were developed without detailed designs. These costs are intended for relative comparison, not for budgeting.

Net interest rate, R, is assumed to be 5 percent.

Key:

SBA = South Bay Aqueduct

SLR = San Luis Reservoir

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5.0 Evaluation of Alternatives

The Full-Barrier and Partial-Protection alternatives were evaluated separately for the SBA and SLR systems using 10 (and in one case, 11) decision-making criteria. Each alternative was assigned a score between 0 and 10 for each criterion. Each decision-making criterion was assigned a weight, and the weighted scores were summed to provide a total score for each alternative. The criteria, scores, and weighting were developed with input from the District from two workshops. The alternative receiving the highest score was ranked the highest and is the recommended alternative for that raw water system.

5.1 Decision-Making Criteria

The selected decision-making criteria are discussed in the following subsections.

5.1.1 Effectiveness of Protection for Vulnerable Equipment

Alternatives were scored according to their ability to protect vulnerable equipment from settlement or damage by invasive mussels. A higher evaluation score indicates greater protection for vulnerable equipment. Vulnerable equipment that was considered include systems for pump cooling water, service water, and fire suppression at the Pacheco, Coyote, and Vasona pump plants.

5.1.2 Effectiveness of Protection for Raw Water System

Alternatives were scored according to their ability to protect the raw water conveyance system (exclusive of the vulnerable equipment described in Section 5.1.1) from settlement or damage by invasive mussels. A higher evaluation score indicates greater protection for the raw water conveyance system.

5.1.3 Effectiveness of Protection for Local Reservoirs, Ponds, and Creeks

Alternatives were scored according to their ability to protect local reservoirs, ponds, and creeks from infestation of invasive mussels. A higher evaluation score indicates greater protection for local reservoirs, ponds, and creeks from infestation of invasive mussels.

5.1.4 Demonstrated Use

Alternatives were scored in proportion to historical demonstration of the control method(s) to meet the intended objectives through practical applications or testing (whereas the scoring of alternatives for criteria described in Sections 5.1.1 through 5.1.3 was based on the theoretical ability to provide protection). High evaluation scores indicate that the control methods have been used by water suppliers to protect drinking water systems or other industries from invasive mussels. Medium evaluation scores indicate that testing has been performed and indicates the potential for success at protecting drinking water systems. Low evaluation scores indicate that testing is being performed, but has not yet been completed or published.

5.1.5 Impacts to the Environment

Alternatives were scored in inverse proportion to the detrimental impacts that they may have to the environment. High evaluation scores indicate little or no impacts to the environment, in general, and receiving waters, specifically. It should be noted that it is assumed that water discharged to local reservoirs will be dechlorinated and/or adjusted for appropriate pH, as necessary.

5.1.6 Impacts to Water Quality

Alternatives were scored in inverse proportion to the detrimental impacts that they may have to the quality of water delivered to customers. High evaluation scores indicate little or no impacts to the quality of water delivered to customers.

5.1.7 Impacts to Water Supply Operations and Planning

Full-Barrier Alternatives were scored in inverse proportion to the detrimental impacts that they may have to the District’s supply or storage capabilities. For example, if San Luis Reservoir was shown to be infested and the local reservoirs were not, the District might choose not to transfer water to local reservoirs unless the alternative was fully protective of local reservoirs. High evaluation scores indicate little or no impacts to the District’s supply or storage capabilities.

5.1.8 Ease of Operating the Alternative

Alternatives were scored in proportion to the ease of operating the control method(s). High evaluation scores indicate that the control methods involve less:

- Operational complexity
- Operator attention
- Maintenance
- Commitment of manpower
- Establishment of new employee positions
- Safety risk to employees

5.1.9 Cost

Alternatives were scored in inverse proportion to the order-of-magnitude cost estimates presented in Section 4. High evaluation scores indicate lower present worth total project costs.

5.1.10 Compatibility of Equipment with Full-Barrier Alternatives

Partial-Protection Alternatives were scored according to the amount of equipment that could later be utilized as part of the selected Full-Barrier Alternative. High evaluation scores indicate a greater compatibility of equipment.

5.1.11 Schedule

Alternatives were scored in inverse proportion to the length of time required for implementation. High evaluation scores indicate that the alternative can be implemented quickly relative to the other alternatives.

5.2 Evaluation Results and Ranking of Alternatives

Evaluation results are presented by system and protection strategy category in the following subsections.

5.2.1 Full-Barrier Alternatives for the SBA System

Table 5-1 shows the relative weights for decision-making criteria and scores for Full-Barrier Alternatives for the raw water system receiving SBA water. Alternative 3 was the highest-scoring Full-Barrier Alternative for the SBA System.

Table 5-1. Evaluation of Full-Barrier Alternatives for the South Bay Aqueduct System

Criteria	Weight	Alternative 1: Filters and Ultraviolet	Alternative 2: Filters and Ferrate	Alternative 3: Filters and Chlorine Dioxide	Alternative 4: Filters and Ozone
Protection for Vulnerable Equipment	14	7	9	9	9
Protection for Raw Water System	14	7	9	9	9
Protection for Recharge Ponds and Creeks	14	7	9	9	9
Demonstrated Use	8	7	3	6	8
Impacts to the Environment	8	9	8	8	8
Impacts to Water Quality	10	10	8	4	5
Impacts to Water Supply Operations and Planning	4	7	9	9	9
Ease of Operating the Alternative	4	7	5	5	4
Cost	15	6	9	10	7
Schedule	5	2	3	4	2
Weighted Score		**678**	**752**	**756**	**723**
Rank		**4**	**2**	**1**	**3**

Alternatives 2, 3, and 4 received equal scores for effectiveness of protection of vulnerable equipment. Alternative 1 received a slightly lower score because UV treatment has no residual and the potential exists for small quantities of untreated water to get through the UV reactors during startup/shutdown/power failures.

Alternatives 2, 3, and 4 received equal scores for effectiveness of protection of the raw water system. Alternative 1 received a slightly lower score because UV treatment has no residual and the potential exists for small quantities of untreated water to get through the UV reactors during startup/shutdown/power failures.

Alternatives 2, 3, and 4 received equal scores for effectiveness of protection of recharge ponds and creeks. Alternative 1 (Filters and UV) received a slightly lower score because UV treatment has no residual and the potential exists for small quantities of untreated water to get through the UV reactors during startup/shutdown/power failures.

None of these alternatives have been used to meet an objective of full-barrier protection for a drinking water system with discharges to surface water. All the scores for the alternatives were discounted to some degree for this fact. The relative order of practical usage and testing related to mussels is, from highest to lowest, ozone, UV irradiation, chlorine dioxide, and ferrate.

None of these alternatives would have much impact on receiving waters because they either carry little or no residual, or would involve dechlorination. Alternative 1 (Filters and UV) was scored the highest because UV has no significant by-products.

Alternative 1 (Filters and UV) scored the highest in terms of water quality because UV irradiation has no significant by-products. Ferrate would likely have no water quality impacts, with the possible exception of iron precipitation if it was overdosed. Chlorite and chlorate would be formed by chlorine dioxide, and bromate would be formed by ozone. It is assumed that the doses would be low enough to avoid formation of by-product concentrations exceeding the MCLs. It would be a fatal flaw for the relevant alternative if bench- or pilot-scale testing demonstrates otherwise.

Alternatives 2 (Filters and Ferrate), 3 (Filters and Chlorine Dioxide), and 4 (Filters and Ozone) received equal scores for impacts to water supply operations and planning. Alternative 1 (Filters and UV) received a slightly lower score. The scores match those assigned for effectiveness of protection of recharge ponds and creeks and use the same rationale.

Alternative 1 (Filters and UV) scored the highest in terms of ease of operations because UV reactors are automated (though they do require attention for lamp replacement). Ferrate, chlorine dioxide, and ozone will require maintenance and attention to the chemical feed for dosing.

Alternative 3 (Filters and Chlorine Dioxide) scored the highest for being the least expensive alternative considered. Alternatives 2 (Filters and Ferrate), 4 (Filters and Ozone), and 1 (Filters and UV) were progressively more expensive, in that order, and were assigned scores in general proportion to their estimated total project cost.

The four alternatives are scored relatively low in terms of schedule because implementation would likely not occur for 3 years or more. These alternatives involve significant changes to the conveyance system (i.e., redistribution of flow through mechanical filters), which would likely require design and construction schedules longer than a year. Pilot testing to confirm effectiveness is recommended for all of the considered alternatives, but particularly ferrate and chlorine dioxide.

5.2.2 Full-Barrier Alternatives for the SLR System

Table 5-2 shows the relative weights for decision-making criteria and scores for Full-Barrier Alternatives for the raw water system receiving San Luis Reservoir water. Alternative 3 was the highest-scoring Full-Barrier Alternative for the SLR System.

Table 5-2. Evaluation of Full-Barrier Alternatives for the San Luis Reservoir System

Criteria	Weight	Alternative 1: Filters and UV	Alternative 2: Filters and Ferrate	Alternative 3: Filters and Chlorine Dioxide	Alternative 4: Filters and Ozone
Protection for Vulnerable Equipment	12	7	9	9	7
Protection for Raw Water System	14	7	9	9	9
Protection for Local Reservoirs, Ponds, and Creeks	16	7	9	9	9
Demonstrated Use	8	7	3	6	8
Impacts to the Environment	8	9	8	8	8
Impacts to Water Quality	10	10	8	4	5
Impacts to Water Supply Operations and Planning	8	7	9	9	9
Ease of Operating the Alternative	4	7	5	5	4
Cost	15	6	9	10	5
Schedule	5	2	3	4	2
Weighted Score		**716**	**803**	**812**	**715**
Rank		**3**	**2**	**1**	**3**

Alternatives 2 and 3 received equal scores for effectiveness of protection of vulnerable equipment. Alternative 1 received a lower score because UV treatment has no residual and the potential exists for small quantities of untreated water to get through the UV reactors during startup/shutdown/power failures. Alternative 4 received a lower score because spot treatments needed to protect equipment upstream of the ozone addition would be slightly less effective.

Alternatives 2, 3, and 4 received equal scores for effectiveness of protection of the raw water system. Alternative 1 received a slightly lower score because UV treatment has no residual and the potential exists for small quantities of untreated water to get through the UV reactors during startup/shutdown/power failures.

Alternatives 2, 3, and 4 received equal scores for effectiveness of protection of local reservoirs, recharge ponds, and creeks. Alternative 1 received a slightly lower score because UV treatment has no residual and the potential exists for small quantities of untreated water to get through the UV reactors during startup/shutdown/power failures.

None of these alternatives have been used to meet an objective of full-barrier protection for a drinking water system with discharges to surface water. All the scores for the alternatives were discounted to some degree for this fact. The relative order of practical usage and testing related to mussels is, from highest to lowest, ozone, UV irradiation, chlorine dioxide, and ferrate.

None of these alternatives would have much impact on receiving waters because they either carry little or no residual, or would involve dechlorination. Alternative 1 was scored the highest because UV has no significant by-products.

Alternative 1 (Filters and UV) scored the highest in terms of water quality because UV irradiation has no significant by-products. Ferrate would likely have no water quality impacts, with the possible exception of iron precipitation if it was overdosed. Chlorite and chlorate would be formed by chlorine dioxide, and bromate would be formed by ozone. It is assumed that the doses would be low enough to avoid formation of by-product concentrations exceeding the MCLs. It would be a fatal flaw for the relevant alternative if bench- or pilot-scale testing demonstrates otherwise.

Alternatives 2 (Filters and Ferrate), 3 (Filters and Chlorine Dioxide), and 4 (Filters and Ozone) received equal scores for impacts to water supply operations and planning. Alternative 1 (Filters and UV) received a slightly lower score. The scores match those assigned for effectiveness of protection of recharge ponds and creeks and use the same rationale.

Alternative 1 (Filters and UV) scored the highest in terms of ease of operations because UV reactors are automated (though they do require attention for lamp replacement). Ferrate, chlorine dioxide, and ozone will require maintenance and attention to the chemical feed for dosing.

Alternative 3 (Filters and Chlorine Dioxide) scored the highest for being the least expensive alternative considered. Alternatives 2 (Filters and Ferrate), 1 (Filters and UV), and 4 (Filters and Ozone) were progressively more expensive, in that order, and were assigned scores in general proportion to their estimated total project cost.

The four alternatives are scored relatively low in terms of schedule because implementation would likely not occur for 3 years or more. These alternatives involve significant changes to the conveyance system (i.e., redistribution of flow through mechanical filters), which would likely require design and construction schedules longer than a year. Pilot testing to confirm effectiveness is recommended for all of the considered alternatives, but particularly ferrate and chlorine dioxide.

5.2.3 Partial-Protection Alternatives for the SBA System

Table 5-3 shows the relative weights for decision-making criteria and scores for Partial-Protection Alternatives for the raw water system receiving SBA water. Alternative 3b was the highest-scoring Partial-Protection Alternative for the SBA System.

Table 5-3. Evaluation of Partial-Protection Alternatives for the South Bay Aqueduct System

Criteria	Weight	Alternative 1: pH Adjustment	Alternative 2a: Chlorine	Alternative 2b: Chlorine Dioxide	Alternative 3a: Potassium (Continuous)	Alternative 3b: Potassium (Periodic)	Alternative 4: Spot Treatments
Protection for Vulnerable Equipment	12	1	2	2	10	8	9
Protection for Raw Water System	12	3	4	4	10	8	0
Protection for Recharge Ponds and Creeks	10	1	2	2	6	3	0
Demonstrated Use	8	1	4	4	4	6	10
Impacts to the Environment	8	9	9	9	5	7	10
Impacts to Water Quality	10	10	2	4	10	10	10
Ease of Operating the Alternative	8	5	7	6	4	8	10
Cost	8	7	7	5	0	8	10
Compatibility with Full-Barrier Alternatives	8	5	9	10	3	3	0
Schedule	16	8	8	8	7	7	10
Weighted Score		**502**	**528**	**532**	**640**	**690**	**688**
Rank		**6**	**5**	**4**	**3**	**1**	**2**

Alternative 3a received the maximum score for effectiveness of protection of vulnerable equipment. Alternatives 3b and 4 were scored 8 and 9, respectively, because the protection would be periodic rather than continuous. Alternative 1 received a lower score because the equipment to be protected (at Vasona Pump Plant) is located downstream of the second pH adjustment (neutralization) point and would not be protected from mussels of any lifestage. Alternatives 2a and 2b received a lower score because the equipment to be protected (at Vasona Pump Plant) are located downstream of the dechlorination point and would not be protected from translocating adult mussels.

Alternative 3a received the maximum score for effectiveness of protection of the raw water system. Alternative 1 received a lower score because portions of the raw water system are located downstream of the second pH adjustment (neutralization) point and would not be protected from mussels of any lifestage. Alternatives 2a and 2b received a lower score because portions of the raw water system are located downstream of the dechlorination point and would not be protected from translocating adult mussels. Alternative 4 will not provide protection to any portions of the raw water system. Alternative 3b received a score of 8 because the protection would be periodic rather than continuous.

None of the Partial-Protection Alternatives will fully protect the recharge ponds and creeks. Alternative 1 received a lower score because the recharge ponds and creeks are located downstream of the second pH adjustment (neutralization) point and may not be protected from mussels of any lifestage. Alternatives 2a (Chlorine) and 2b (Chlorine Dioxide) received a lower score because the recharge ponds and creeks are located downstream of the dechlorination point and would not be protected from translocating adult mussels. Alternative 3a (Continuous Potassium Addition) received the highest score of the four alternatives because potassium in the conveyance system may kill some mussels entering the system, and residual potassium in the receiving waters, even at low concentrations, may make conditions intolerable for some mussels. Alternative 3b (Periodic Potassium Addition) may periodically make conditions in the recharge ponds and creeks intolerable for some or all settled mussels, depending on the resulting concentration of potassium. Alternative 4 (Spot Treatments) will not provide protection to the recharge ponds and creeks.

Alternative 4 received the maximum score for demonstrated use, as spot treatments have been a common solution for utilities in the Great Lakes region. Alternative 1 (pH adjustment) received the lowest score because high pH adjustment has never been implemented and has been tested only to a very limited extent. Alternatives 2a, 2b, 3a and 3b received only moderate scores as these control methods have been used in the past for control or eradication of mussels but not to meet objectives similar to the District’s.

Alternative 4 (Spot Treatments) received the maximum score for impacts to the environment, because it could be implemented without resulting in any chemical addition to receiving waters. Alternatives 1 (pH adjustment), 2a (Chlorine), and 2b (Chlorine Dioxide) also received high scores, under the assumption that pH neutralization or dechlorination before discharge would largely prevent impacts to receiving waters. Alternative 3a (Continuous Potassium Addition) was scored the lowest because potassium has been shown to affect other bivalves than dreissenid mussels and therefore may impact native populations in receiving waters. Alternative 3b (Periodic Potassium Addition) was scored higher than Alternative 3a because it may be possible to use this alternative during a 52-day period when water is not released to reservoirs or creeks with native bivalves.

Alternatives 1 (pH adjustment), 3a (Continuous Potassium Addition), 3b (Periodic Potassium Addition), and 4 (Spot Treatments) received the maximum score for impacts to water quality, because no degradation of water quality is anticipated. Alternative 2a (Chlorine) was scored the lowest because chlorine forms DBPs. It is possible that THMs would be formed at concentrations that would exceed the Stage 2 DBP rule. Alternative 2b (Chlorine Dioxide) was scored relatively low because chlorine dioxide forms DBPs such as chlorite.

Alternative 4 received the maximum score in terms of ease of operations because it is assumed that the spot treatments will require infrequent attention. Alternatives 1, 2a, and 2b were scored lower because the feed rates for chlorine and caustic soda will depend not only on the volume of water to be treated, but also on the water quality conditions. Alternative 3a was scored lowest because the chemical would be supplied in solid form and operations staff expressed concerns at a March 2011 workshop about the level of effort associated with solids handling. Alternative 3b was scored relatively high because it will only be operated for 52 days out of the year.

Alternative 4 (Spot Treatments) scored the highest for being the least expensive alternative considered. Alternatives 3b (Periodic Potassium Addition), 2a (Chlorine), 1 (pH adjustment), 2b (Chlorine Dioxide), and 3a (Continuous Potassium Addition) were progressively more expensive, in that order, and were assigned scores in general proportion to their estimated total project cost.

Alternative 2b (Chlorine Dioxide) received the maximum score for compatibility of equipment with Full-Barrier Alternatives because all of its elements are incorporated into the highest-ranking Full-Barrier Alternative. Alternative 2a (Chlorine) scored relatively high because sodium hypochlorite is a feed chemical for both ferrate and chlorine dioxide and because the chemical injection equipment could be used for both the Partial-Protection and Full-Barrier alternatives. Alternative 1 (pH adjustment) received a medium score because of the chemical injection equipment and the fact that caustic soda is a feed chemical for ferrate. Alternatives 3a and 3b received relatively low scores, on the assumption that only the chemical feed equipment could be reused. Alternative 4 (Spot Treatments) received the lowest possible score because it was assumed that none of the spot treatment equipment would be reused.

Alternative 4 received the maximum score for schedule because it could be implemented relatively quickly and is not necessary until after mussels are detected in the system. The other three alternatives received similar scores, because design and construction should be similar for each. Alternatives 3a and 3b received the lowest scores of the options considered, because it is not known how quickly regulatory approval for addition of potassium could be granted.

5.2.4 Partial-Protection Alternatives for the SLR System

Table 5-4 shows the relative weights for decision-making criteria and scores for Partial-Protection Alternatives for the raw water system receiving San Luis Reservoir water. Alternative 3b was the highest-scoring Partial-Protection Alternative for the SLR System.

Table 5-4. Evaluation of Partial-Protection Alternatives for the San Luis Reservoir System

Criteria	Weight	Alternative 1: pH Adjustment	Alternative 2a: Chlorine	Alternative 2b: Chlorine Dioxide	Alternative 3a: Potassium (Continuous)	Alternative 3b: Potassium (Periodic)	Alternative 4: Spot Treatments
Protection for Vulnerable Equipment	12	3	4	4	10	8	9
Protection for Raw Water System	12	3	4	4	10	8	0
Protection for Calero Reservoir	8	2	3	3	4	0	0
Protection for Recharge Ponds and Creeks	8	1	2	2	6	3	0
Demonstrated Use	7	1	4	4	4	6	10
Impacts to the Environment	7	9	9	9	5	7	10
Impacts to Water Quality	9	9	2	4	10	10	10
Ease of Operating the Alternative	7	5	7	6	4	8	10
Cost	7	7	8	5	0	9	10
Compatibility with Full-Barrier Alternatives	7	5	9	10	3	3	0
Schedule	16	8	8	8	7	7	10
Weighted Score		**494**	**541**	**538**	**634**	**649**	**638**
Rank		**6**	**4**	**5**	**3**	**1**	**2**

Alternative 3a received the maximum score for effectiveness of protection of vulnerable equipment. Alternatives 3b and 4 were scored 8 and 9, respectively, because the protection would be periodic rather than continuous. Alternative 1 received a lower score because the equipment to be protected (at Coyote Pump Plant and Vasona Pump Plant) are located downstream of the second pH adjustment (neutralization) point and would not be protected from mussels of any lifestage. Alternatives 2a and 2b received a lower score because the equipment to be protected (at Coyote Pump Plant and Vasona Pump Plant) are located downstream of the dechlorination point and would not be protected from translocating adult mussels.

Alternative 3a received the maximum score for effectiveness of protection of the raw water system. Alternative 1 received a lower score because portions of the raw water system are located downstream of the second pH adjustment (neutralization) point and would not be protected from mussels of any lifestage. Alternatives 2a and 2b received a lower score because portions of the raw water system are located downstream of the dechlorination point and would not be protected from translocating adult mussels. Alternative 4 will not provide protection to any portions of the raw water system. Alternative 3b received a score of 8 because the protection would be periodic rather than continuous.

None of the Partial-Protection Alternatives will fully protect Calero Reservoir. Alternative 1 received a lower score because the reservoir is located downstream of the second pH adjustment (neutralization) point and would not be protected from mussels of any lifestage. Alternatives 2a and 2b received a lower score because the reservoir is located downstream of the dechlorination point and would not be protected from translocating adult mussels. Alternative 3a received the highest score of the four alternatives because potassium in the conveyance system may kill some mussels entering the system, and residual potassium in the receiving waters, even at low concentrations, may make conditions intolerable for some mussels. Alternatives 3b (Periodic Potassium Addition) and 4 (Spot Treatments) will not provide protection to Calero Reservoir.

None of the Partial-Protection Alternatives will fully protect the recharge ponds and creeks. Alternative 1 (pH adjustment) received a lower score because the recharge ponds and creeks are located downstream of the second pH adjustment (neutralization) point and would not be protected from mussels of any lifestage. Alternatives 2a (Chlorine) and 2b (Chlorine Dioxide) received lower scores because the recharge ponds and creeks are located downstream of the dechlorination point and would not be protected from translocating adult mussels. Alternative 3a (Continuous Potassium Addition) received the highest score of the four alternatives because potassium in the conveyance system may kill some mussels entering the system, and residual potassium in the receiving waters, even at low concentrations, may make conditions intolerable for some mussels. Alternative 3b (Periodic Potassium Addition) may periodically make conditions in the recharge ponds and creeks intolerable for some or all settled mussels, depending on the resulting concentration of potassium. Alternative 4 (Spot Treatments) will not provide protection to the recharge ponds and creeks.

Alternative 4 received the maximum score for demonstrated use, as spot treatments have been a common solution for utilities in the Great Lakes region. Alternative 1 (pH adjustment) received the lowest score because high pH adjustment has never been implemented and has been tested only to a very limited extent. Alternatives 2a, 2b, 3a and 3b received only moderate scores as these control methods have been used in the past for control or eradication of mussels but not to meet objectives similar to the District's.

Alternative 4 (Spot Treatments) received the maximum score for impacts to the environment, because it could be implemented without resulting in any chemical addition to receiving waters. Alternatives 1 (pH adjustment), 2a (Chlorine), and 2b (Chlorine Dioxide) also received high scores, under the assumption that pH neutralization or dechlorination before discharge would largely prevent impacts to receiving waters. Alternative 3a (Continuous Potassium Addition) was scored the lowest because potassium has been shown to affect other bivalves than dreissenid mussels and therefore may impact native populations in receiving waters. Alternative 3b (Periodic Potassium Addition) was scored higher than Alternative 3a because it may be possible to use this alternative during a 52-day period when water is not released to reservoirs or creeks with native bivalves.

Alternatives 1 (pH adjustment), 3a (Continuous Potassium Addition), 3b (Periodic Potassium Addition), and 4 (Spot Treatments) received the maximum score for impacts to water quality, because no degradation of water quality is anticipated. Alternative 2a (Chlorine) was scored the lowest because chlorine forms DBPs. It is possible that THMs would be formed at concentrations that would exceed the Stage 2 DBP rule. Alternative 2b (Chlorine Dioxide) was scored relatively low because chlorine dioxide forms DBPs such as chlorite.

Alternative 4 received the maximum score in terms of ease of operations because it is assumed that the spot treatments will require infrequent attention. Alternatives 1, 2a, and 2b were scored lower because the feed rates for chlorine and caustic soda will depend not only on the volume of water to be treated, but also on the water quality conditions. Alternative 3a was scored lowest because the chemical would be supplied in solid form and operations staff expressed concerns at a March 2011 workshop about the level of effort associated with solids handling. Alternative 3b was scored relatively high because it will only be operated for 52 days out of the year.

Alternative 4 (Spot Treatments) scored the highest for being the least expensive alternative considered. Alternatives 3b (Periodic Potassium Addition), 2a (Chlorine), 1 (pH adjustment), 2b (Chlorine Dioxide), and 3a (Continuous Potassium Addition) were progressively more expensive, in that order, and were assigned scores in general proportion to their estimated total project cost.

Alternative 2b (Chlorine Dioxide) received the maximum score for compatibility of equipment with Full-Barrier Alternatives because all of its elements are incorporated into the highest-ranking Full-Barrier Alternative. Alternative 2a (Chlorine) scored relatively high because sodium hypochlorite is a feed chemical for both ferrate and chlorine dioxide and because the chemical injection equipment could be used for both the Partial-Protection and Full-Barrier alternatives. Alternative 1 (pH adjustment) received a medium score because of the chemical injection equipment and the fact that caustic soda is a feed chemical for ferrate. Alternatives 3a and 3b received relatively low scores, on the assumption that only the chemical feed equipment could be reused. Alternative 4 (Spot Treatments) received the lowest possible score because it was assumed that none of the spot treatment equipment would be reused.

Alternative 4 received the maximum score for schedule because it could be implemented relatively quickly and is not necessary until after mussels are detected in the system. The other three alternatives received similar scores, because design and construction should be similar for each. Alternatives 3a and 3b received the lowest scores of the options considered, because it is not known how quickly regulatory approval for addition of potassium could be granted.

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6.0 Recommendations

This section presents the recommended protection strategies and the steps needed for implementation.

6.1 Recommended Protection Strategies

Full-Barrier Alternative 3, Mechanical Filters and Chlorine Dioxide, is the recommended Full-Barrier Alternative for both the SBA and SLR systems. Alternative 2, Mechanical Filters and Ferrate, was ranked second highest and should be considered if chlorine dioxide proves unable to meet the District's objectives. However, there are many data gaps associated with each of these alternatives and testing is needed to answer questions related to their implementation. The District should meet with the California Department of Public Health as soon as possible to present the results of this evaluation and communicate the District's plan for implementation.

Partial-Protection Alternative 3b, Periodic Potassium Feed, is the recommended Partial-Protection Alternative for both the SBA and SLR systems.

The intake trash racks on the San Luis Reservoir intakes need to be protected from settlement by dreissenid mussels and, because they are upstream of the designated control points, they will not be protected by the Full-Barrier or Partial-Protection alternatives. It is recommended that new intake trash racks, with a biofouling-resistant coating and vertical bars instead of a bar grid, be installed. Protection of the trash racks could be maximized by having removable trash racks and spares. Having more than one set of removable trash racks per intake would allow for more efficient and safer cleaning at the surface.

The total project costs to build and operate the recommended alternatives are significant. However, the costs resulting from mussel infestation in the District's raw water system, reservoirs, creeks, and recharge ponds without an existing protection strategy could also be significant. Such costs could be incurred through short-term and long-term responses, operational interruptions, and replacement of equipment or facilities. It is recommended that the District develop an estimate of costs that would be incurred if mussels arrive in source water before a protection strategy is in place. This information would be valuable during the process of deciding whether or not to proceed with the recommended protection strategies.

6.2 Bench- and Pilot-scale Testing

The primary by-product of feeding chlorine dioxide is chlorite, which is regulated by EPA and the California Department of Public Health at 1 mg/L. To assess whether feeding chlorine dioxide for mussel control is feasible without exceeding the regulatory standard, bench-scale testing, using SBA and SLR water, will be necessary to determine the demand and decay for chlorine dioxide and the resulting chlorite formation. Pilot testing will also be necessary to determine the necessary dose and contact time for chlorine dioxide to kill 100 percent of mussel veligers. It is recommended that similar testing with ferrate and potassium be performed in parallel in case the necessary chlorine dioxide dose is prohibitively high.

San Justo Reservoir is the closest location for pilot-scale testing at a water body that contains dreissenid mussels (in this case, zebra mussels). There are plans to use potassium to eradicate mussels from the reservoir, but the eradication efforts are not yet scheduled and are not expected to occur until after the summer of 2011.

Taste tests, using finished water with a range of concentrations of potassium, are recommended to help the District define upper limits of acceptable potassium concentrations.

6.3 Design

Conceptual designs of systems for mechanical filtration and addition of chlorine dioxide and periodic potassium feed have been prepared for the SBA and SLR systems (MWH, 2011). Detailed designs should be developed once bench- and pilot-scale testing supports the protection strategies.

6.4 Implementation

Ideally, the selected Full-Barrier Alternative will be operational prior to dreissenid mussel infestation of the District's imported source water. However, it is anticipated that a Full-Barrier Alternative will not be operational for three years or longer. In order to minimize the negative consequences that could occur if the District's source water becomes infested with mussels before then, it is recommended that the District design and construct the selected Partial-Protection Alternative. Operation of the Partial-Protection Alternative is not recommended unless mussels become established in imported source water or the District's raw water system prior to implementation of the Full-Barrier Alternative.

If mussels are detected in the District's source water or system before a Full-Barrier or Partial-Protection alternative is operational, the District should consider all options for minimizing the spread of mussels through the raw water system and whether any of the control measures described in this report may be implemented as a temporary solution more quickly than the selected Partial-Protection Alternative. Spot treatments for vulnerable equipment should be considered until the selected protection alternative is operational. Implementation of one of the Reactive Mitigation Alternatives may be necessary if mussels become established downstream of the recommended control measures in the District's raw water system or local reservoirs.

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APPENDIX A

Mechanical Filters

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HYDAC INTERNATIONAL

AutoFilt® RF3 Automatic Self-Cleaning Filter

www.hydacusa.com

DESIGN

The AutoFilt® RF3 is an automatic self-cleaning filtration system designed for continuous maintenance-free filtration for all major manufacturing and processing industries. It removes solid contamination from low viscosity fluids such as water and machine tool coolants. Its rugged construction and self-cleaning feature provide companies with increased machinery reliability resulting in reduced operating, labor and maintenance costs.

Superior removal of contamination particles from water is accomplished with Slotted Tube / Wedge Wire Filter Elements ranging from 50 to 3,000 microns and SuperMesh™ Filter Elements with 25 and 40 microns.

The automatic self-cleaning process begins, as soon as, the filter elements become contaminated. Due to the unique single element cleaning process, the total filtered flow is not reduced during the cleaning process.

Flow rates range can range from 20-31,000 GPM and housings are available with ANSI mounting port flanges from 2” to 36”.

HYDAC can supply numerous combinations of housing materials, as well as, system operating equipment to reach the optimum installation for every industry application.

COST EFFECTIVENESS

Particle contamination in water accelerates the rate of wear on system components such as spray nozzles, water valves, and pipelines. This could result in premature component failure.

The use of automatic self-cleaning filters lead to a significant decrease in service and maintenance intervals resulting in time and labor savings. As well, costs for replacement equipment and waste disposal can be minimized.

Process water is typically contaminated with solids and water companies apply surcharges to handle the contaminant discharge. The HYDAC AutoFilt® RF3 is ideally suited for removing these contaminants prior to discharge thus reducing or eliminating any financial surcharge.

TECHNICAL DATA

Flow Rates
- 20 - 31,000 gpm

ANSI Flange Sizes
- 2” - 36”

Filtration Micron Ratings
- 25 - 3000 µm

Maximum Operating Pressure
- 90 to 150 psi*

Power Source
- Electric, Pneumatic, or Electro-pneumatic

Power Requirements
- 480 3-phase VAC*
- 80 psi air pressure

Filter Housing Material
- Carbon Steel
- Stainless Steel 316Ti

Internal Parts
- Stainless Steel 304

Self-Cleaning Valve
- Stainless Steel akin 316

Filter Elements
- Stainless Steel 316L

Corrosion Protection for Carbon Steel Vessel
- Polyurethane
- Rubber coating

Special Coatings and Steels are Available for Severe Fluid Applications

Filter Vessel Certification
- ASME Code available

*Other Models Available, Consult Factory

Model Code: Filter Assembly

RF3 5 EPT NG N 1 3 0 / KS1000 5 12345678 ___

Filter Type

RF3 = AutoFilt®

Filter Size

		Flow Range (GPM)	ANSI Flange
C	=	20 - 120	2”
0	=	110 - 500	4”
1	=	400 - 1120	6”
2	=	880 - 1980	8”
2.5	=	1760 - 2600	10”
3	=	2420 - 3780	12”
4	=	3550 - 7480	16”
5	=	6600 - 10,780	20”
6	=	8800 - 15,850	24”
7	=	13,200 - 22,000	28”
8	=	19,800 - 31,000	36”

Drive Control / Connecting Voltage

EPT = Electric / Pneumatic cycle control, Δp dependent
EU = Electric control, Δp dependent
PT = Pneumatic cycle control, Δp dependent, size C-4
PTZ = Pneumatic cycle timed control, size C-4
7 = 3X415V/N/PE 60Hz
8 = 3X460V/X/PE 60Hz

Housing Material / Corrosion Protection

N = Standard steel 1.0038, outside primed
NM = Standard steel 1.0038, outside primed, inside metallogal® painted *(Polyurethane)*
NG = Standard steel 1.0038, outside primed, inside rubber coated *(Butyl Coated)*
E = Stainless steel 1.4571
A = with ANSI-flanged, additional A at the end

Shut-Off Valve Material

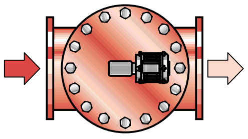
N = Standard steel
E = Stainless steel

Differential Pressure Gauge

1 = Pressure chamber, Aluminum 3.258302
2 = Pressure chamber, Stainless steel 1.4305
3 = with pressure mediators stainless steel 315 TI

Flange Position Inlet & Outlet

1 = outlet opposite inlet *(standard)*
2 = outlet turned 90° clockwise direction compared to standard
3 = outlet turned 180° clockwise direction compared to standard
4 = outlet turned 270° clockwise direction compared to standard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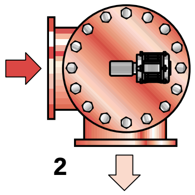
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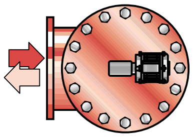
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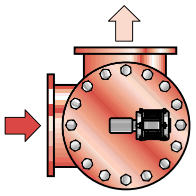
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Modification Number

Element Set

KD25 = Conical SuperMesh™
KD40 = Conical SuperMesh™
KS50 = Conical slotted tubes *(wire wedge)*
KS100 = Conical slotted tubes *(wire wedge)*
KS200 = Conical slotted tubes *(wire wedge)*
KS300 = Conical slotted tubes *(wire wedge)*
KS400 = Conical slotted tubes *(wire wedge)*
KS500 = Conical slotted tubes *(wire wedge)*
KS1000 = Conical slotted tubes *(wire wedge)*
KS1500 = Conical slotted tubes *(wire wedge)*
KS2000 = Conical slotted tubes *(wire wedge)*
KS2500 = Conical slotted tubes *(wire wedge)*
KS3000 = Conical slotted tubes *(wire wedge)*

Size of Element Set

Use same code selected in **filter size**

Drawing Number

(omit) = standard version
For special versions a number will be provided after technical clarification at head office

Vessel Certification

(omit) = standard version
ASME = ASME version

OPERATION

The design of the AutoFilt® RF3 Self-Cleaning Filter is simple yet highly effective. The basic construction consists of the main housing, inlet and outlet ports with flanged connections, filter elements, outlet valve and actuator and electronic operating controls. All of these combined together provide a completely automated self-cleaning filtration system.

The process begins with fluid passing through the inlet flange reaching the filter elements by flowing from inside the element to outside. Solid contamination is then trapped on the inside of the Wedge-Wire filter element. As contamination increases, the differential pressure between the contaminated and clean side increases. When the set differential pressure is reached, 7 psid typical, self-cleaning process is triggered.

Note: This self-cleaning activation has an adjustable differential pressure or time setting. (see *Starting the Automatic Self-Cleaning Process* on page 6.)

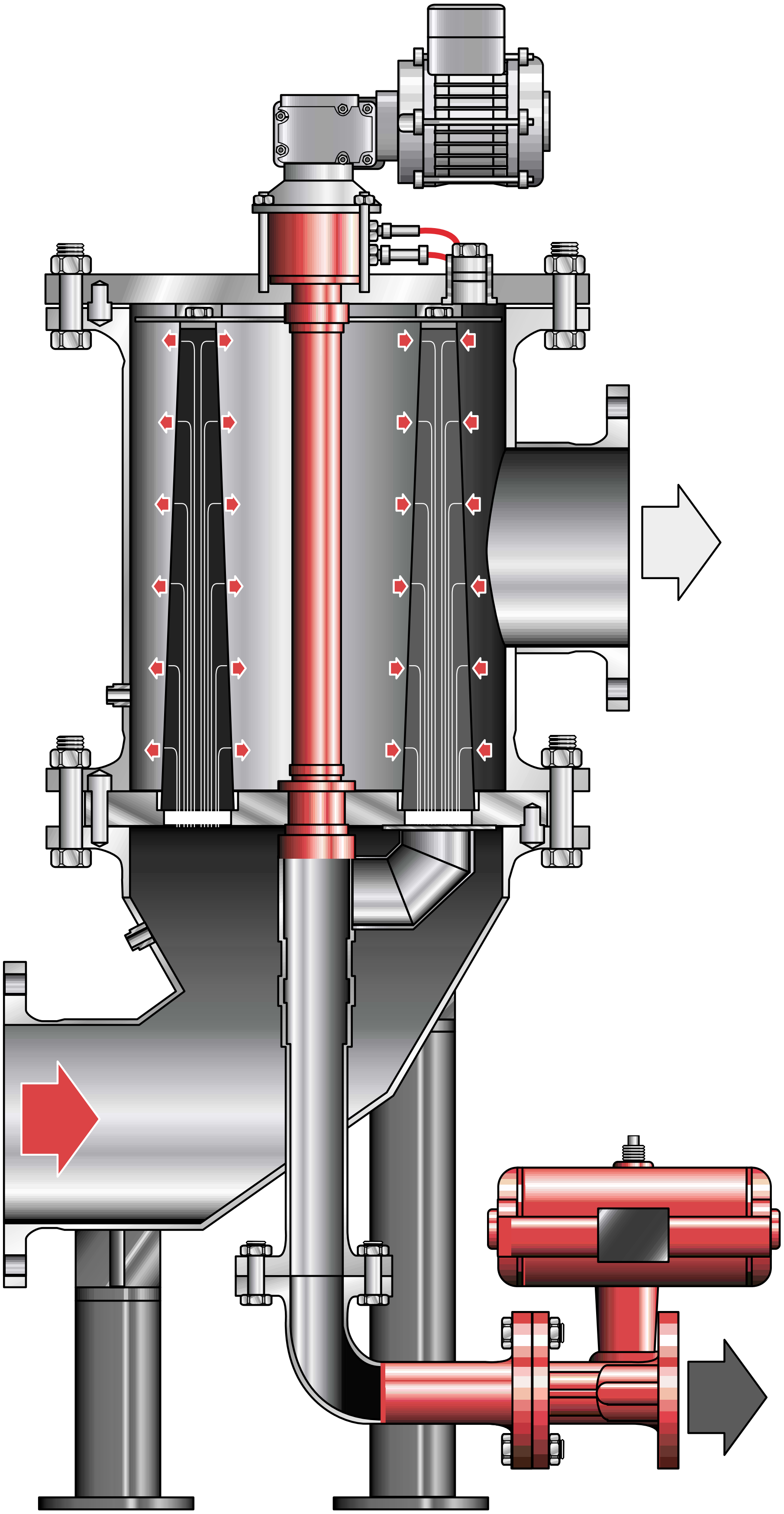
The self-cleaning process is one complete cycle which cleans one element at a time in succession. The geared motor turns the contamination discharge arm under the filter element to be cleaned. The contamination discharge valve is then opened by an actuator. This results in a high pressure drop within the filter element being cleaned, which forces the particles into the discharge line. During this operation, only a small amount of clean fluid is used to complete the cleaning process.

A typical self-cleaning cycle takes less than 30 seconds. The cleaning cycle takes place with no interruption in flow or pressure drop.

The unique conical element design and internal mounting configuration allows for smooth flow transition, resulting in a minimal pressure loss during the cleaning process.

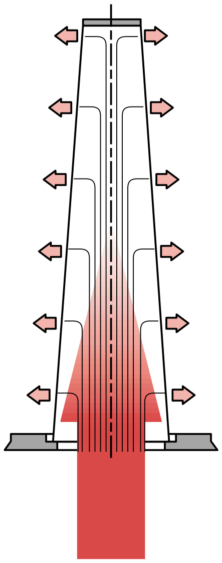
Advantage to the customer: Fewer self-cleaning cycles and a minimum loss of flushing fluid.

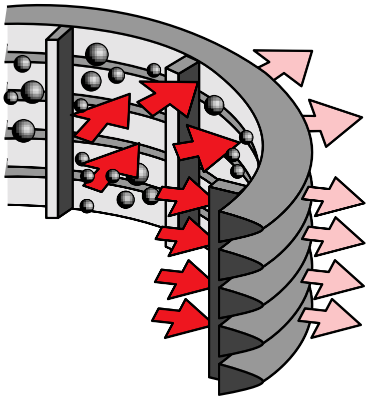
Cutaway: RF3



Element Filtering:

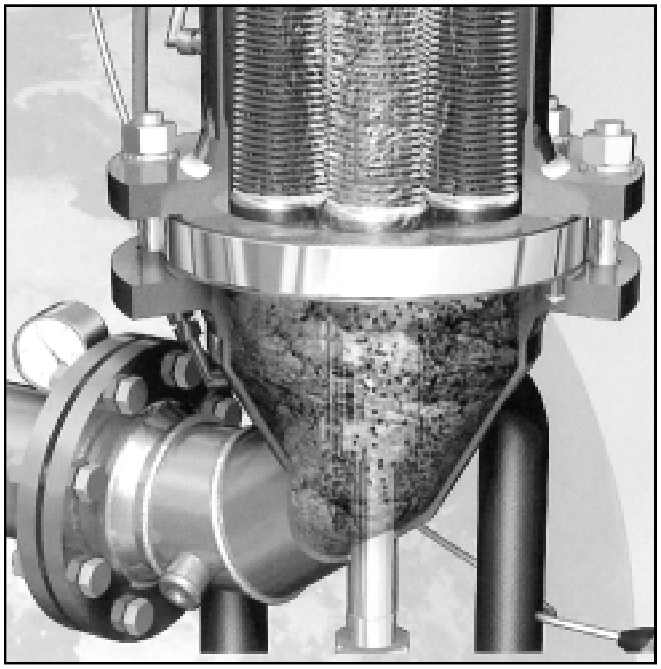
Inside to Outside





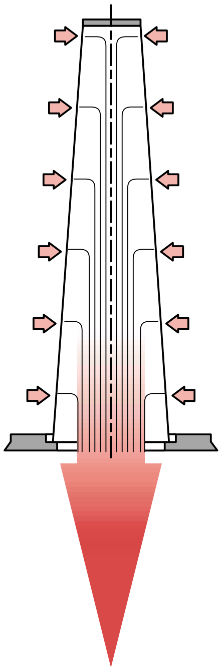
Vessel Filtration:

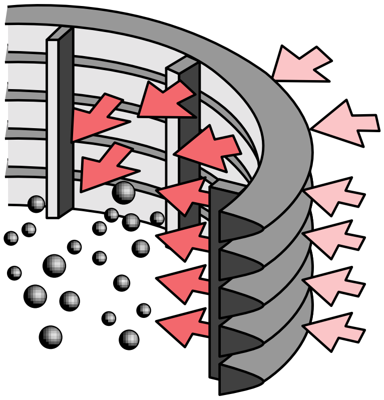
Inside to Outside



Element Back-Flushing:

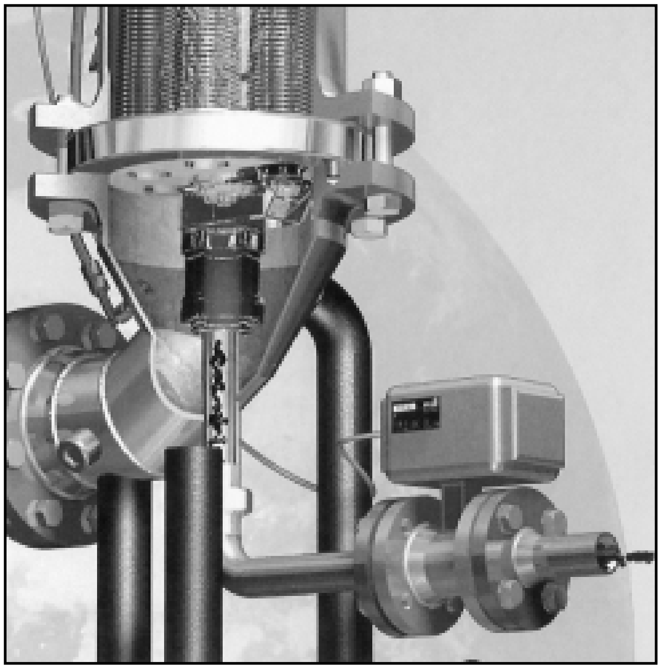
Outside to Inside





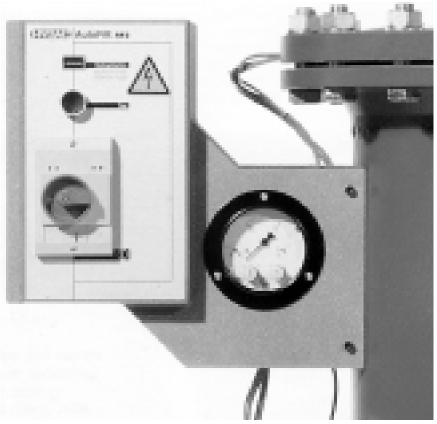
Vessel Self-Cleaning:

Outside to Inside



Starting The Automatic Self-Cleaning Process

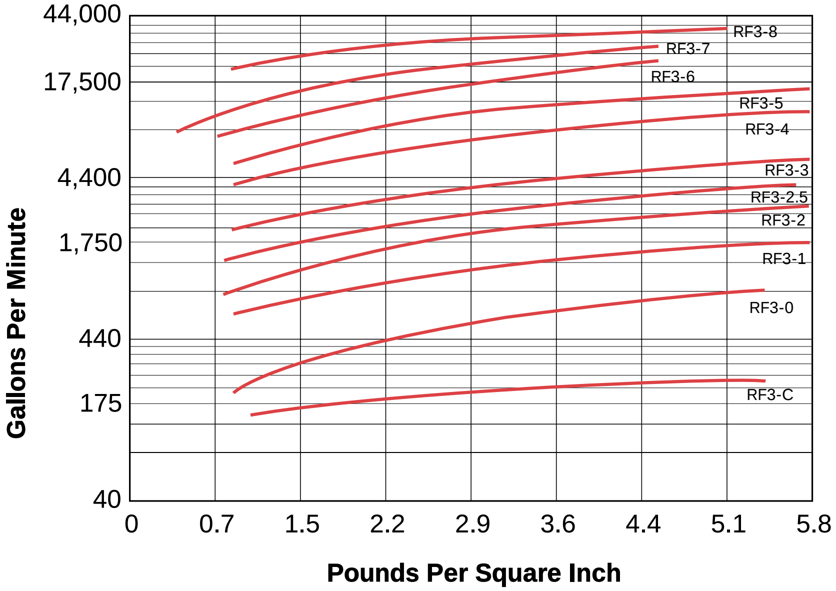
- Pressing the Test Button on the Control Panel
- Electrically activated Test Button
- Differential Pressure set point is exceeded, e.g., 7 psid
- Adjustable Timer, e.g., 12 hours
- Combination Differential Pressure and Adjustable Timer



Ready To Operate

The filter control unit and differential pressure measuring lines are already connected. Once the inlet, outlet, and discharge lines have been attached, only the power and/or air supply need to be connected.

Flow Curves



Note: The curves are for filter rating from 100 µm - 3000 µm. For 50 µm the pressure drop increases by 30%. This is true for sizes RF3 0 - 8. For RF3 C there is no increase in pressure drop. For 25, 40, and 50 µm the pressure drop increases by 30%.

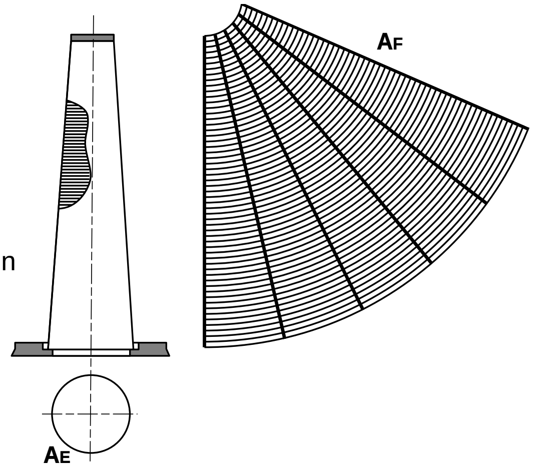
Element Opening Quotient

EFQx determines consistent flow without reverse flow through the filter element during the filtering and self-cleaning process. The EFQx value is the ratio of the opening filtration surface of an element to the cross section of the opening of the element inlet.

$$EFQ_x = \frac{A_F}{A_E}$$

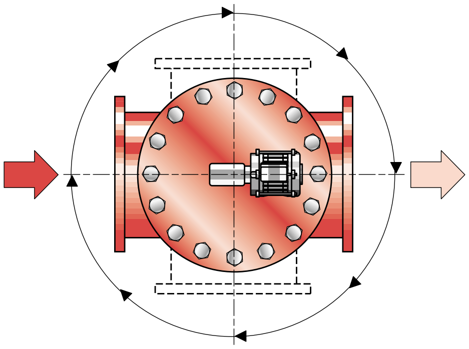
X = Filtration rating in µm

Example: $EFQ_{100} < 3$ for elements with filtration rating of 100 µm



Variable Filter Geometry

The outlet flange can be oriented in any 90˚ increment in comparison to the inlet. The discharge line incorporates a slip flange which enables positioning at any angle in which the housing legs do not interfere. The AutoFilt RF3 can be easily integrated into any plant due to these flexible mounting options.



Filter Elements

Types and Micron Ratings

- Slotted tube *(Wedge-Wire)* 50 - 3000 µm
- SuperMesh™ 25 and 40 µm

Advantages of the AutoFilt® RF3	...and the Benefits to You!
Extensive standard features for numerous applications	Excellent price to performance ratio
Automatic operation	Reliable and safe Set it & Forget it Low operating costs
Continuous fluid flow during self-cleaning	No interruption of unit operation Minimum fluid loss
Flow rate up to 31,000 gpm	High process performance
Service friendly	Low maintenance & replacement part costs
Isokinetic filtration and cleaning	Maximum utilization of filter surface area Full filtration performance after cleaning process
Conical filter elements	Minimal Dp curve Optimum EFQx
Slotted-tube filter elements	Long service life Optimum filtration and cleaning properties
Pulse-aided cleaning	Additional dynamic element cleaning with low loss of cleaning fluid
Adjustable controls	Customer-specific for numerous applications
Flow-optimized filtration	High flow characteristics in compact dimensions
Static sealing between contaminated and clean sides	Guaranteed high filtration quality
Variable housing isometry	Reduced costs due to space saving and simple installation
Numerous equipment options	Customer specific for numerous applications
Ready to operate unit	Simple installation and commissioning
ISO 9001 certification	High quality & performance standards

APPLICATIONS

WATER PLANTS:
AutoFilt® RF3 installed as a 1st stage filter for the removal of sand and debris from underground water. Extended life is provided to the cartridge elements protecting reverse osmosis systems.

PROCESS WATER:
AutoFilt® RF3 is used to remove solid contamination from incoming river and lake process water. Protection is provided to critical plant operating components. As well, the AutoFilt® RF3 can be used to filter discharge water, thus reducing and/or eliminating excessive water company surcharges.

POWER PLANTS:
AutoFilt® RF3 is used to remove scale from water protecting cooling generators. Filtration of the power plant sealing water will increase the service life of turbine shaft sliding-ring seals.

COOLING TOWERS:
AutoFilt® RF3 is used to filter water used in cooling towers to prevent the clogging of the condensers.

STEEL INDUSTRY:
AutoFilt® RF3 is used to protect nozzles and pumps during the high pressure descaling process. In addition, protection is provided during the cooling process for blast furnaces and rolling mills.

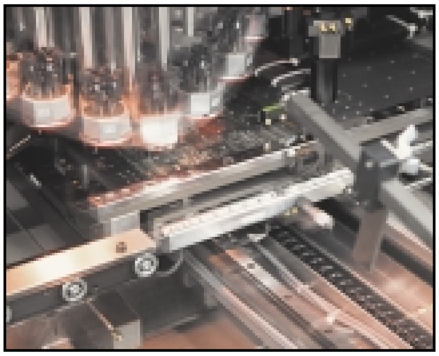
PAPER INDUSTRY:
AutoFilt® RF3 is used to protect nozzles from becoming clogged on paper machines.

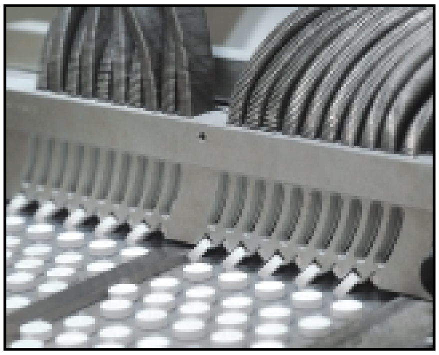
MACHINE TOOLS:
AutoFilt® RF3 is used to filter cooling lubricants used on machine tools.

STEAM SUPPLY:
AutoFilt® RF3 is used to remove piping scale protecting the heat exchangers.

FOOD INDUSTRY:
AutoFilt® RF3 is used to filter supplied municipal water used in food processing.

CHEMICAL PLANTS:
AutoFilt® RF3 is used to filter process water used by chemical plants for cooling and production.





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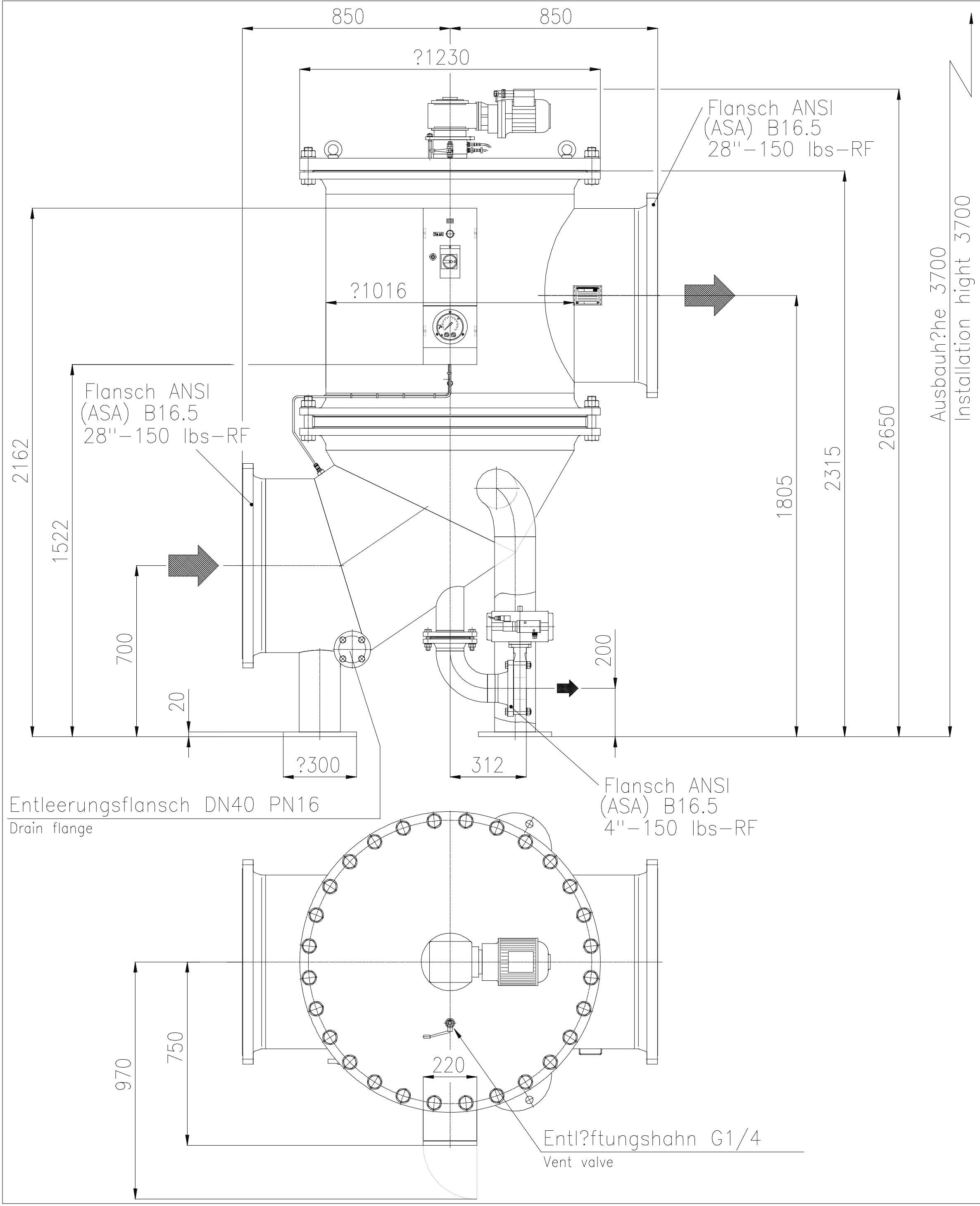
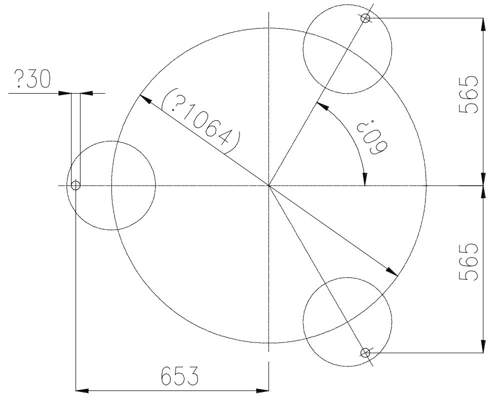
HYDAC PROCESS FILTRATION
2260 City Line Road • Bethlehem, PA 18017
Phone (610) 266-0100 • Fax (610) 264-3540
www.hydacusa.com • sales@hydacusa.com



Techn. Daten
Technical data

Zul. Betriebs?berdruck Allowable operating pressure	: 6 bar
Zul. Betriebstemperatur Allowable operating temperature	: 90 ?C
Anzahl Filterelemente Number of filterelements	: 44
Filterfeinheit Filtration rating	: 50-3000 ?m
Filterelement Filterelement	: Spaltrohr slotted tube
Gewicht Weight	: 1950 kg (leer) (empty)
Inhalt Volume	: Ca. 1355 l

Befestigungsl?cher
Fixing points



Die in der Zeichnung angegebenen Ma?e
The dimensions indicated in the drawing
sind mit ?5 mm toleriert.
tolerated with ?5 mm.

Allgemeintoleranzen ISO 2768					
L?ngenma?e					
?ber bis	0,5 6 ?0,1	6 30 ?0,2	30 120 ?0,3	120 400 ?0,5	400 1000 ?0,8

Werkst?ckkanten DIN 6784 - . + .

Rundungshalbmesser Fasen, Winkel
Form und Lage Genauigkeitsgrad angeben! Wenn nicht gilt "H"
Genauigkeitsgrad "m" H ○ K ○ L ○
Pa?ma?e
Abma?e

2 c	28.03.02 27.03.02	HAUSDORF KUHN I.	642997
1 b	04.05.01 03.05.01	HAUSDORF KUHN I.	625873
1 a	25.01.00 20.01.00	HAUSDORF KUHN I.	618981
Anz. Index	gepr.am ge?nd.am	gepr.von ge?nd.von	?.M.Nr.

2000	Tag	Name
Gez.	13.01.	MOLITOR M.
Gepr.	13.01.	HAUSDORF
Norm.	.	.

Werkstoff
Teile-Nr.
Fertigma?e

Rauheitsklasse DIN ISO 1302									
?m	N2	N3	N4	N5	N6	N7	N8	N9	N10
Rz	0,25	0,5	1	2	4	8	16	32	63
Ra	0,05	0,1	0,2	0,4	0,8	1,6	3,2	6,3	12,5

Ma?stab 1:12
Modell-Nr.
Zeichnung besteht aus 1 Blatt
Blatt: 1
Masse 0.000 kg

HYDAC FILTERTECHNIK

Auftrag-Nr.

Benennung

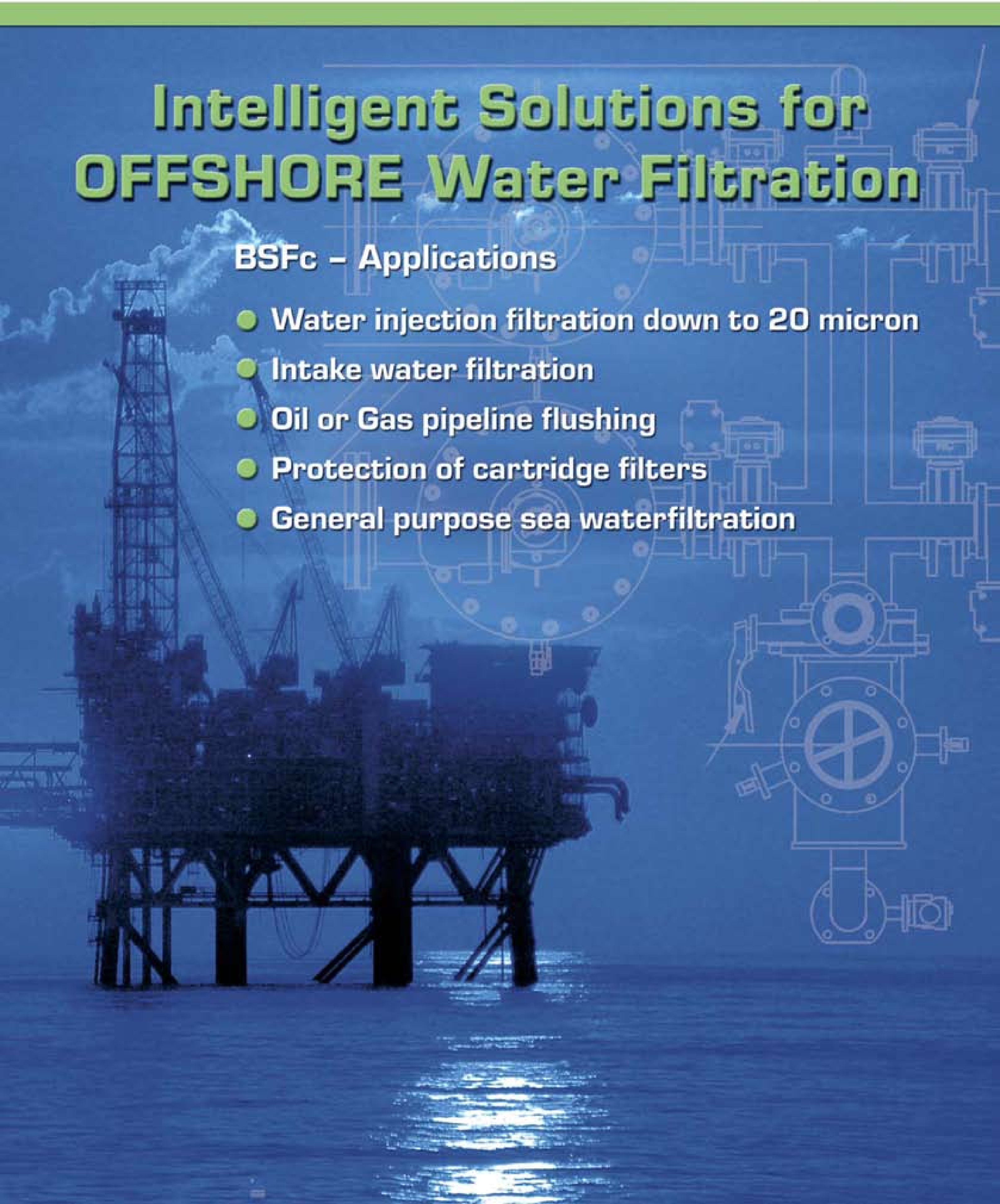
Rueckspuelfilter
RF3-7-EPT/ANSI

Teile-Code-Nr.
07 710 972 2 03034444
Ers. f?r:
Ers. durch:

Schutzvermerk nach DIN 34 beachten !

Computererstellte Zeichnung (CAD)

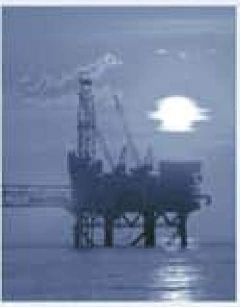
BallastSafe™ Filtration company



Intelligent Solutions for OFFSHORE Water Filtration

BSFc – Applications

- Water injection filtration down to 20 micron
- Intake water filtration
- Oil or Gas pipeline flushing
- Protection of cartridge filters
- General purpose sea waterfiltration



Defend the Deep with BSFc: The Filter Port of Call

BSFc - Offshore Filtration

BSFc designs, manufactures and supplies a wide range of offshore filtration products for the offshore industry. Providing application solutions such as water injection, pipeline flushing and protection of cartridge filters. We also provide filter solutions and services for use in other sea water applications such as Ballast Water Treatment. BSFc manufactures under ISO 9001 and can provide filters built according to ASME standard (ASME built), and to DNV-OS-D101.

Efficient Filtration down to 20 micron

BSFc top-flight technologies are designed for combating sea water's marine bio-invasions, requiring cutting-edge components with proven performance levels.

The BSFc Electric Filter lies at the heart of each system, playing a pivotal role in the removal of micro-organisms, Phyto, Zooplankton and general suspended solids. By incorporating Ballast Safe's Electric Filters into your system, you equip the most efficient sea water filtering technology on the market.

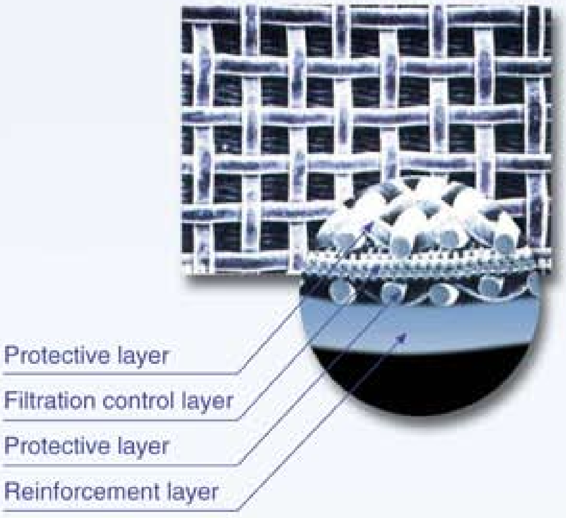
Clean water is essential to maximise the productivity of the producing oil reservoir. Suspended solids have major negative effects on the permeability of the oil well, which results in signicicant reduction in oil production and the lifetime of the producing well.

Unique Screen Technology for an Unparalleled ZOOPLANKTON Removal Rate

BSFc's fine screen is composed of four sintered, stainless steel screen layers that create a strong, reinforced filtering element, requiring no support.

Two types of stainless steel are available:

- 316L for standard applications.
- 316L with special® protection for high corrosion resistance requirements.



BallastSafe™ Filtration company

Two Stages for Comprehensive Filtration

In order to ensure thorough filtration of water, BSFc's Automatic Electric Filter undergoes two filtration stages:

Coarse Filtration

To prevent large objects – such as fish and foreign material – from entering the filter's cleaning mechanism in the filtration chamber, coarse filtering is carried out in the inlet chamber (optional).

Fine Filtration

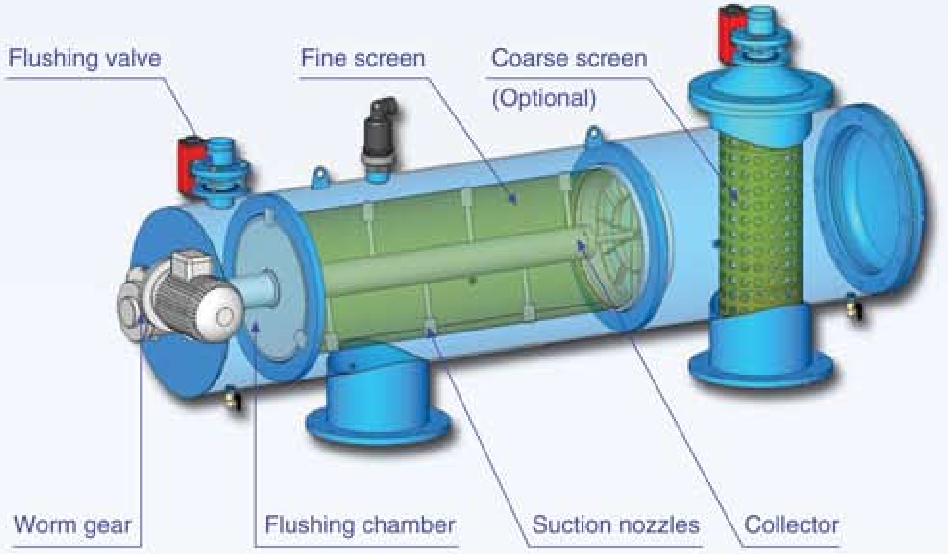
Once the raw water passes through the coarse screen it emerges through the fine screen and flows into the system. The filtering process creates a "cake" of sediment on the fine screen's surface. This sediment improves filtration efficiency by enhancing the fine screen's effectiveness. The filtration process creates differential pressure across the screen that rises as the "cake" enlarges, until a pre-determined value is reached (normally 0.5 bar) to activate the flushing process.

Self-Cleaning Action for Automatic Dirt Removal

BSFc uses either a DP pressure switch/gauge or a timer to automatically activate a self-cleaning action. This cleaning action entails suctioning dirt off the fine screen and flushing it out.

Once a flushing command is given, the flushing valve opens to the atmosphere, causing a pressure drop in the flushing chamber that suctions dirt off the fine screen through the collector and flushing valve. Simultaneously, the worm-gear of the electric motor spins the collector in a helical motion. The suction nozzles move across the entire screen surface while cleaning the clogged screen.

The Programmable Logic Controller (PLC) monitors the process and, where necessary, activates intensive flushing cycles to overcome a heavy dirt load in the raw water.

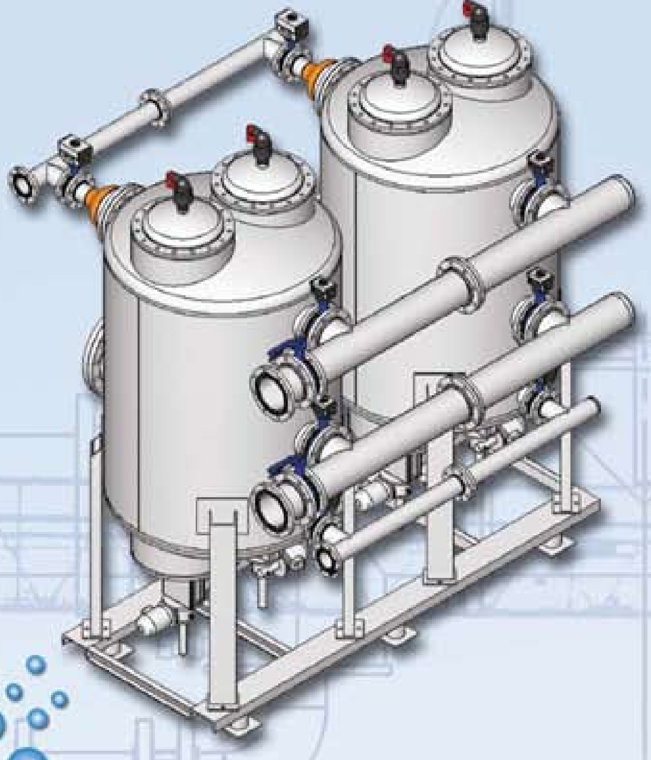


BSFc Specifications

- Minimum operating pressure: 21 psi (1.5 bar)
- Maximum operating pressure: 150 psi (10 bar)
- Electric power: 3-phase VAC, 50/60 Hz
- Temperature range: 0ºC - 50ºC
- Exhaust valve: Pneumatically actuated butterfly valve
- Filter housing: Carbon steel with SMO fitting or Stainless Steel

BSFc's Automatic Electric Filter is made of the following materials:

- Housing coating: 300 micron protective coating, extra durable polyester applied electrostatically and oven-cured on a zinc phosphate layer, inside and outside, for maximum anti corrosion resistance
- Screen: stainless steel 316L (Special® protection is optional)
- Seals: Synthetic rubber
- Internal parts: Stainless steel & PVC, Teflon, Erlite



BallastSafe™ **Filtration company**

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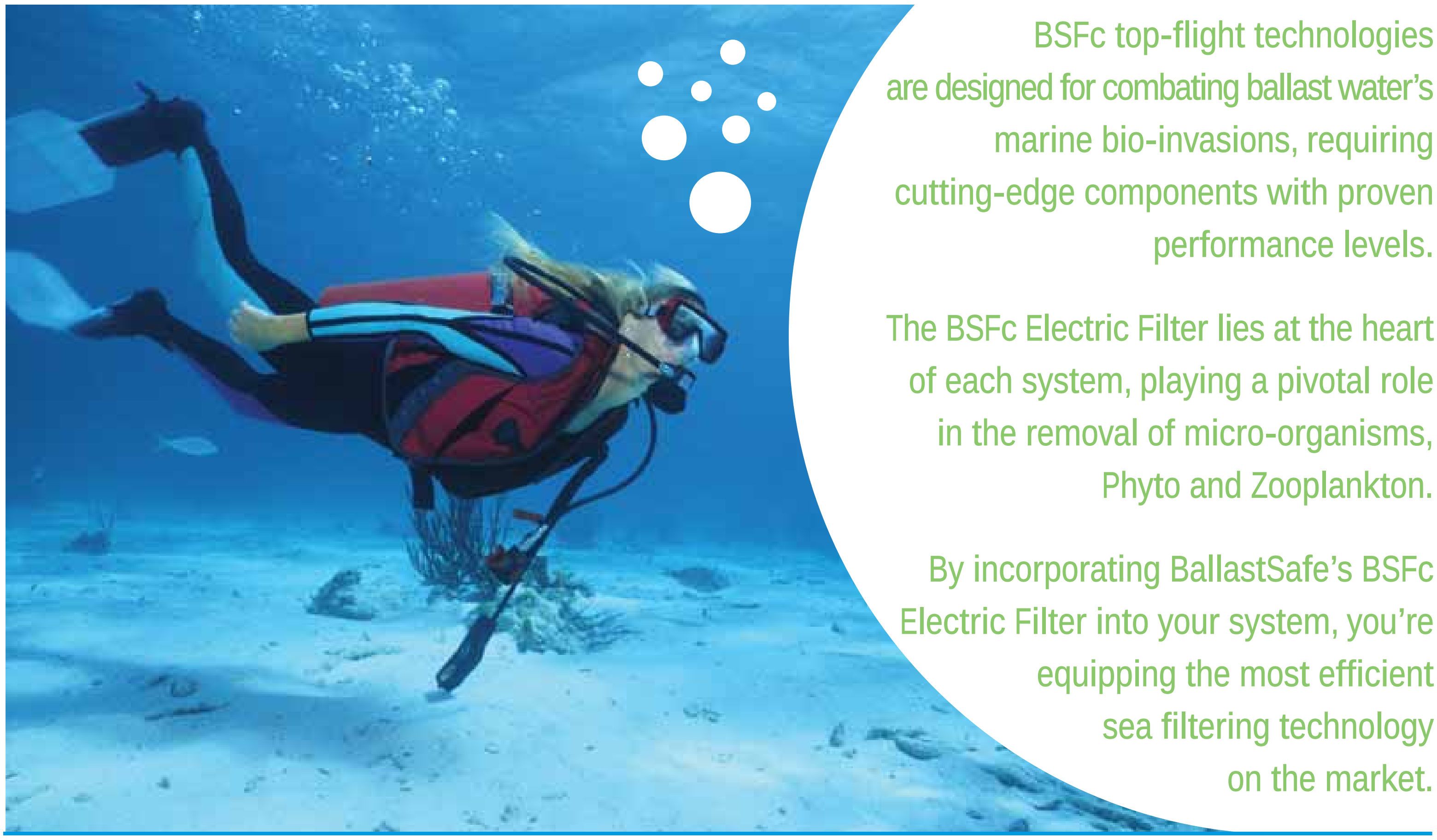
www.ballastsafe.com

BallastSafe™ Filtration company

The filter port of call

Put Your Technology at the Forefront of Ballast Water Management



BSFc top-flight technologies are designed for combating ballast water's marine bio-invasions, requiring cutting-edge components with proven performance levels.

The BSFc Electric Filter lies at the heart of each system, playing a pivotal role in the removal of micro-organisms, Phyto and Zooplankton.

By incorporating BallastSafe's BSFc Electric Filter into your system, you're equipping the most efficient sea filtering technology on the market.

BallastSafe's BSFc Automatic Electric Filter: On-Target ZOOPLANKTON & Sediment Removal Plus a Full Self-Cleaning Action

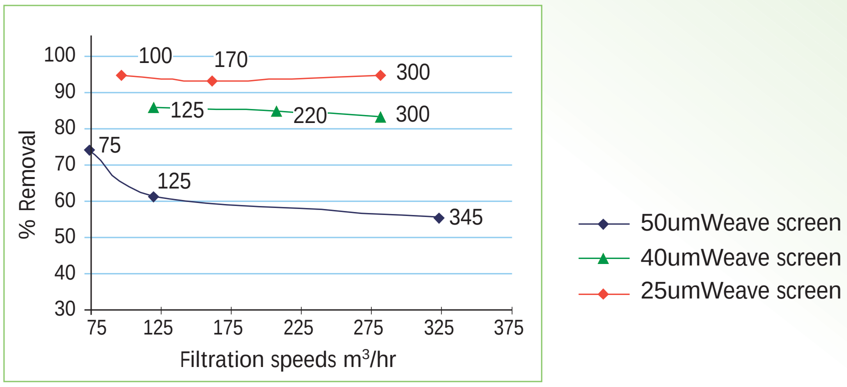
BSFc Electric Filter's unique screen technology enables it to have an unparalleled Zooplankton removal rate. Made out of 4 layers of sintered stainless steel screens, it is a reinforced filtering element requiring absolutely no support. BallastSafe's BSFc Electric Filter is the market's only filter featuring a self-flushing action on the part of the primary strainer. In addition, its unique configuration allows it to be installed either vertically or horizontally.

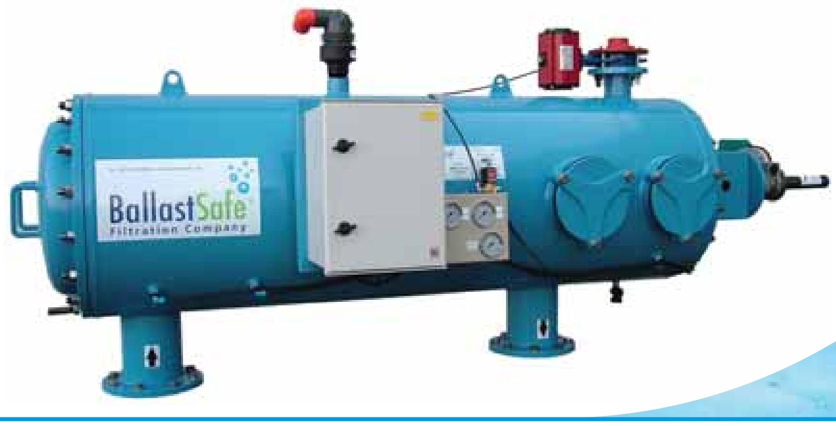
Extensive NIOZ Testing Proves BSFc is a Superior Filter

Trials conducted at NIOZ (Royal Netherlands Institute for Sea Research)* at Texel island on the North Sea confirm that BallastSafe's BSFc Electric Filter is superior in its Zooplankton removal rate; retention of organic material; ability to operate under low pressure conditions; recovering capacity from "high dirt load" situations; and has a low percentage use of flush water.

* Detailed summary available upon request

Summary of Zooplankton retention rates Vs Filtration Speeds





Developed in the Country Known for Advanced Water Solutions

Israel – the country that made the desert bloom – is known as a source for quality water solutions. Maximizing the potential of a minimal water supply, Israel is responsible for introducing drip irrigation technology to the world and pioneering the concept of a national water conduit. Today, Israel is poised to play a major role in developing and advancing sophisticated water technologies that effectively address a host of global problems. Ballast water management is one of them.

BallastSafe: A Member of Israel's Water Technology Community

BallastSafe manufactures its cutting-edge BSFc filter at one of the largest filter and water treatment manufacturing plants in Israel. With 180 employees and located in the heart of Israel's central region, this state-of-the-art plant is equipped with sophisticated cutting and welding robotics technology, a modern coating facility and a strict QA system adhering to ISO 9001:2000.

A Heavy Emphasis on R&D

A company solely dedicated to ballast and other seawater mechanical filtration applications, BallastSafe™ places a heavy emphasis on R&D in order to provide superior solutions. Its Product Development Department is staffed by a team of engineers and industry experts who design filters specifically created for the BWT market. Taking into consideration all unique aspects and requirements of this new and demanding market, the team custom-designs filters meeting specific market requirements and analyzes them in the company's state-of-the-art testing facility. Finally, before placing any filter on the market, BallastSafe conducts "field" tests in; Europe's North Sea, Oslo Fiord and Germany's Elba River, Port of Cape Town in South Africe and Newcastle University in the UK.

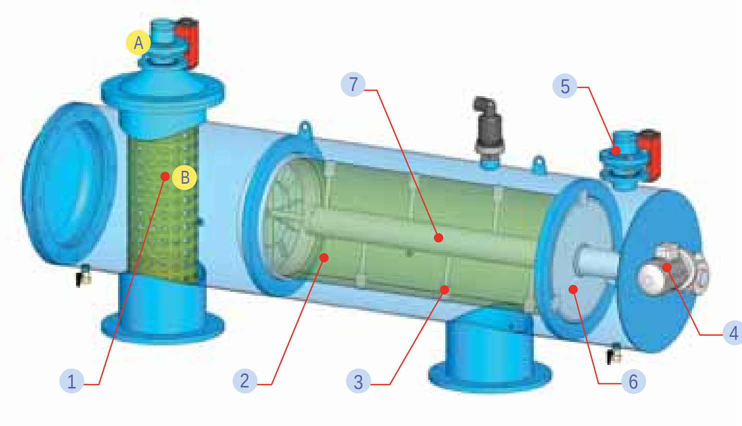
BSFc: Features

- Fine Screen Filter made from sintered, multi-layered stainless steel; does not require support.
- Especially designed to remove organic matter to meet D-2 standard.
- Significantly larger open screen area.
- Exceedingly effective self-cleaning process automatically activated by DP pressure switch/gauge or timer.
- Continuous cleaning of large volumes of dirt load during the ballasting process without interruption.
- Reversible screw system for smooth, reliable and rapid cleaning of the entire screen surface.
- Coarse screen self-flushing action ensuring a trouble-free operation for longer time periods (optional).

Defend the Deep with BSFc: The Filter Port of Call

Two Stages for Comprehensive Filtration

In order to ensure thorough filtration of ballast water, BSFc's Automatic Electric Filter undergoes two filtration stages:



Ⓐ Flushing Valve for coarse screen (optional)
Ⓑ Self-flushing coarse screen (optional)

1

Coarse Filtration

To prevent large objects – such as fish and foreign material – from entering the filter's cleaning mechanism in the filtration chamber, coarse filtering is carried out in the inlet chamber ①.

2

Fine Filtration

Once the raw water passes through the coarse screen ① it emerges through the fine screen ② and flows into the system. The filtering process creates a "cake" of sediment on the fine screen's surface. This sediment improves filtration efficiency by enhancing the fine screen's effectiveness. The filtration process creates differential pressure across the screen that rises as the "cake" enlarges, until a predetermined value is reached (normally 0.5 bar) to activate the flushing process.

Self-Cleaning Action for Automatic Dirt Removal

BSFc uses either a DP pressure switch/gauge or a timer to automatically activate a self-cleaning action. This cleaning action entails suctioning dirt off the fine screen and flushing it out. Once a flushing command is given, the flushing valve ⑤ opens to the atmosphere, causing a pressure drop in the flushing chamber ⑥ that suctions dirt off the fine screen through the collector ⑦ and flushing valve. Simultaneously, the worm-gear ④ of the electric motor spins the collector in a helical motion. The suction nozzles ③ move across the entire screen surface while cleaning the clogged screen. The Programmable Logic Controller (PLC) monitors the process and, where necessary, activates intensive flushing cycles to overcome a heavy dirt load in the raw water. In cases of low operating pressures and generated suction forces not reaching the required minimum level, a small suction pump can be added to the flush line to assist the cleaning process (see page 7). This is a reliable and inexpensive addition to the system, enabling the BSFc filter to operate under extremely low pressures of only 1.2 bar.

Unique Screen Technology for an Unparalleled ZOOPLANKTON Removal Rate

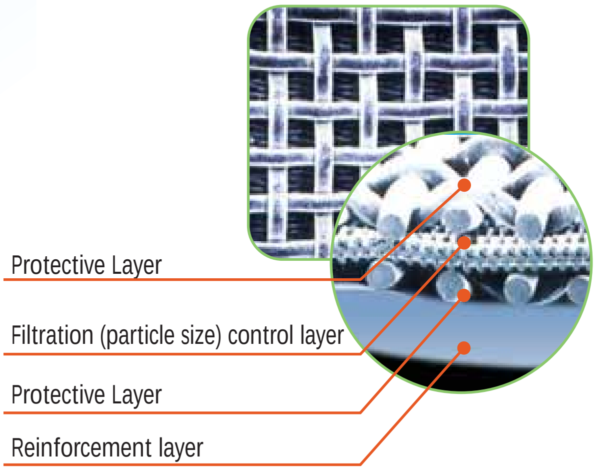
BSFc's fine screen is composed of four sintered, stainless steel screen layers that create a strong, reinforced filtering element requiring no support

Two types of stainless steel are available:

- 316L for standard applications.
- 904L for high corrosion protection requirements.

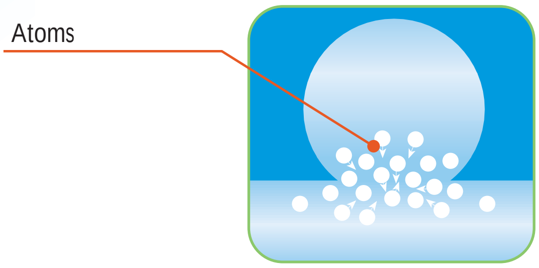
Available screens

micron	400	300	200	150	120	100	80	50	30	20	10
mesh	40	50	80	100	120	150	200	300	450	500	600



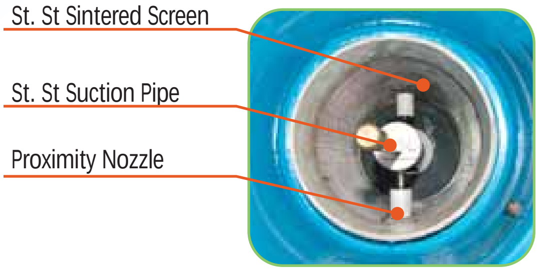
Importance of the Sintering Process

When metals are maintained at a temperature that is near their melting point for a set period of time, metallic counter diffusion occurs at the micro-structural level of the metal contact points. A crystal formation takes place between the metals to form a completely integrated structure. This ensures outstanding strength and enhanced durability.



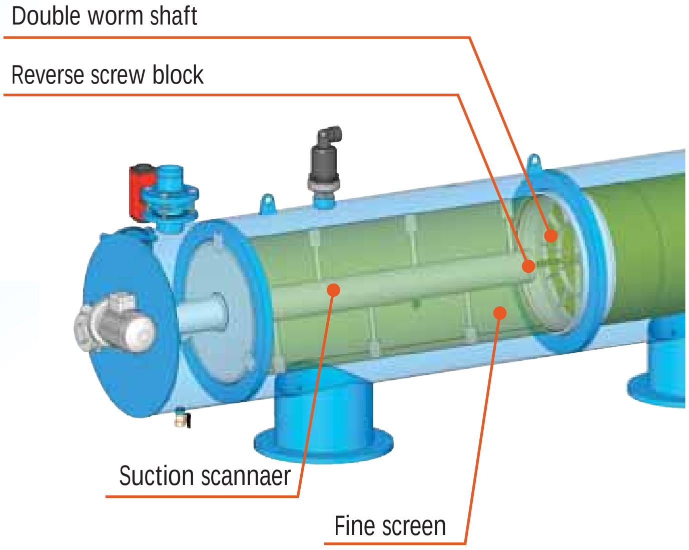
Proximity Nozzles for Maximum Suction Force

Specially designed proximity nozzles enable a close proximity of the nozzles to the screen during the cleaning suction operation. They are hydraulically operated, ensuring maximum suction force for removing dirt from the screen. In addition, they are able to use minimal amounts of water for the cleaning process. Consequently, compared to other technologies on the market, BSFc uses a significantly lower amount of "wasted water" during the filtration's flushing process.



Reversible Screw System for a Reliable, Continuous Flush Mode

BSFc's reversible screw system enables it to maintain high reliability under continuous flush mode operations. It eliminates micro-switch assistance and the necessity to change direction of the electric motor's direction.



Low Level of "Wasted Water" Used for Cleaning Process

BSFc is a water saver. Its PLC ensures effective cleaning while maintaining a low level of "wasted water" during the filtration process.

Installation & Operation

BSFc Ballast water filter's Physical Characteristics (Horizontal Configuration)

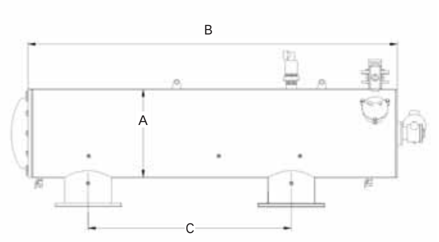
Model	In/Out Connections		*Flow rates up to		Dimension A		Dimension B		Dimension C		Weight	
	Inch	mm	gpm	m^3/hr	Inch	mm	Inch	mm	Inch	mm	lbs.	Kg
BSFc-H-0.25	2.3	50, 80	220	50	12	300	77	1925	2.9	430	355	160
BSFc-H-0.4	3, 4	80, 100	440	100	12	300	87.4	2185	23.6	600	385	174
BSFc-H-0.6	6, 8	150, 200	770	175	16	400	98	2450	30.7	780	620	280
BSFc-H-0.8	6, 8	150, 200	1,056	240	16	400	110	2750	39	990	725	330
BSFc-H-1.0	8,10,12	200,250, 300	1,320	300	18	450	122.4	3,060	48	1,200	880	400
BSFc-H-1.6	10,12, 14	250,300, 350	2,112	480	24	600	99.76	2,494	56	1,400	1,034	470
BSFc-H-2.0	12,14, 16	300,350, 400	2,640	600	48	1200	115.2	2,880	56	1,200	2,611	1,187
BSFc-H-3.0	12,14, 16,18	300,350, 400,450	3,960	900	48	1200	115.2	2,880	56	1,200	2,809	1,277
BSFc-H-3.2	14,16, 18,20	350,400, 450,500	4,400	1,000	56	1400	99.76	2,494	56	1,200	3,146	1,430
BSFc-H-4.8	16,18, 20,24	400,450, 500, 600	6,600	1,500	56	1400	99.76	2,494	56	1,200	3,366	1,530
BSFc-H-6.4	16,18, 20,24	400,450, 500, 600	8,800	2,200	61	1524	102.16	2,554	56	1,200	4,840	2,200
BSFc-H-9.6	16,18, 20,24	400,450, 500, 600	13.200	3,000	88	2200	107.76	2,694	56	1,200	7,700	3,500

BSFc Ballast water filter's Physical Characteristics (Vertical Configuration)

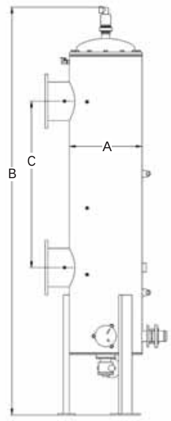
Model	In/Out Connections		*Flow rates up to		Dimension A		Dimension B		Dimension C		Weight	
	Inch	mm	gpm	m^3/hr	Inch	mm	Inch	mm	Inch	mm	lbs.	Kg
BSFc-V-0.25	2, 3	50, 80	220	50	12	300	83.2	2080	12.9	430	355	175
BSFc-V-0.4	3, 4	80, 100	440	100	12	300	93.6	2340	23.6	600	385	190
BSFc-V-0.6	6, 8	150, 200	770	175	16	400	110	2750	30.7	780	620	300
BSFc-V-0.8	6, 8	150, 200	1,056	240	16	400	122.16	3054	39	990	725	350
BSFc-V-1.0	8,10,12	200,250, 300	1,320	300	18	450	137.2	3,430	48	1,200	924	420
BSFc-V-1.6	10,12, 14	250,300, 350	2,112	480	24	600	137.2	3,130	56	1,400	1,078	490
BSFc-V-2.0	12,14, 16	300,350, 400	2,640	600	48	1200	137.2	3,430	56	1,200	2,720	1,237
BSFc-V-3.0	12,14, 16,18	300,350, 400,450	3,960	900	48	1200	137.2	3,430	56	1,200	2,899	1,318
BSFc-V-3.2	14,16, 18,20	350,400, 450,500	4,400	1,000	56	1400	141.44	2,995	56	1,200	3,267	1,485
BSFc-V-4.8	16,18, 20,24	400,450, 500, 600	6,600	1,500	56	1400	141.44	2,995	56	1,200	3,465	1,575
BSFc-V-6.4	16,18, 20,24	400,450, 500, 600	8,800	2,000	61	1524	123.8	3,095	56	1,200	4,840	2,200
BSFc-V-9.6	16,18, 20,24	400,450, 500, 600	13,200	3,000	88	2200	141.4	3,231	56	1,200	7,700	3,500

*.All quoted flow rates are subject to water quality, filtration degree and TSS removal rate requirements

Horizontal Configuration

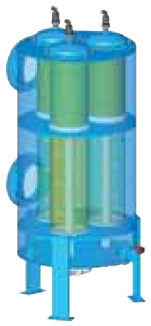


Vertical Configuration



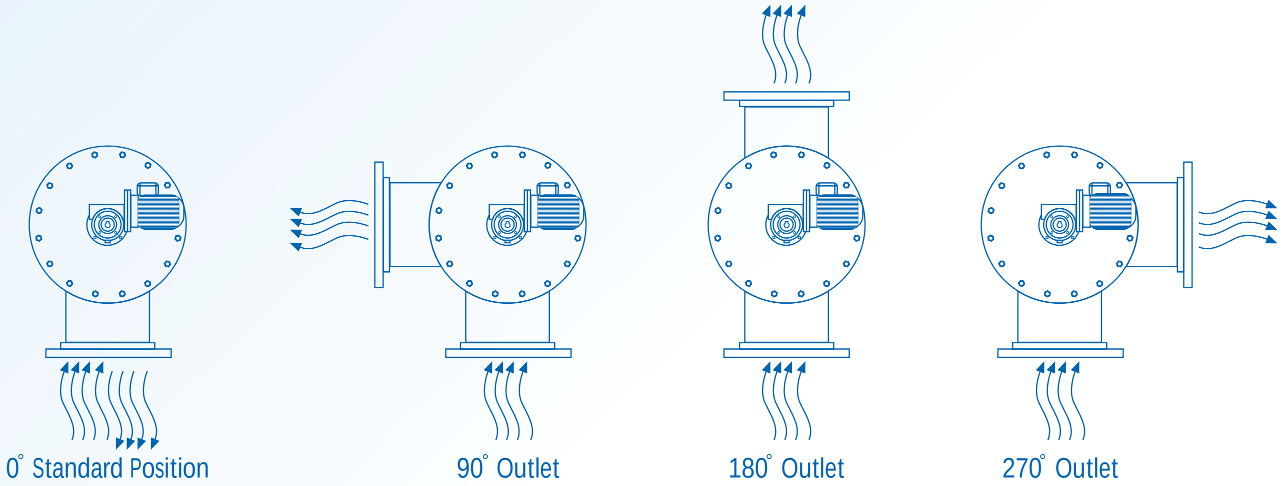
Typical foot print

Filter Unit	Vertical Filter vessel Foot print	Horizontal Filter vessel Foot print	Weight
	m^2	m^2	Ton
BSFc-1.0, 300 m3/hr (Max.)	0.2	1.14	0.4
BSFc-1.6, 480 m3/hr (Max.)	0.3	1.53	0.5
BSFc-2.0, 600 m3/hr (Max.)	1.13	3.06	1.18
BSFc-3.0, 900 m3/hr (Max.)	1.13	3.06	1.28
BSFc-3.2, 1000 m3/hr (Max.)	1.55	3.6	1.43
BSFc-4.8, 1500 m3/hr (Max.)	1.55	3.6	1.53
BSFc-6.4, 2000 m3/hr (Max.)	1.81	3.85	2.2
BSFc-9.6, 3000 m3/hr (Max.)	4.5	5.95	3.5



Inlet & Outlet flange configuration

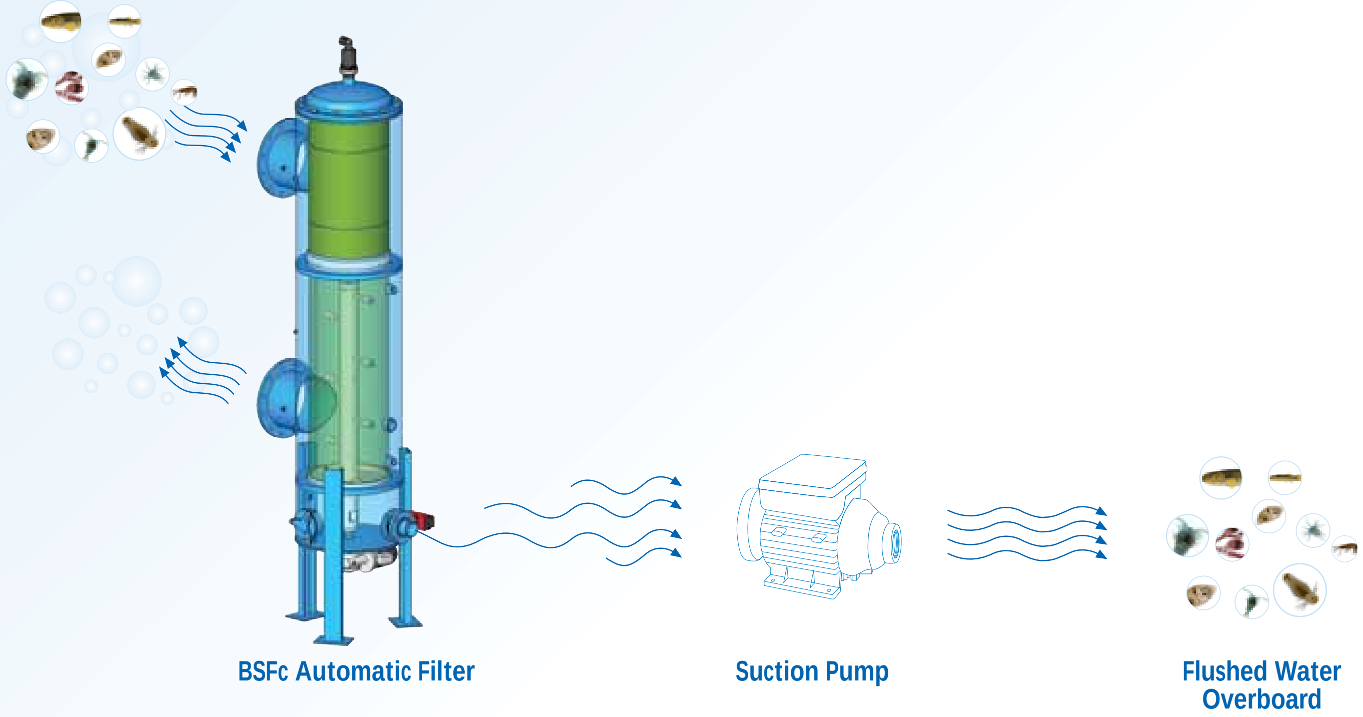
- BSFc Automatic Electric Filters can be installed either horizontally or vertically. The IN/OUT flange connection positions can be fitted in four different directions to suit your space and piping arrangement: 0º, 90º, 180º and 270º.
- When low operating pressure situations is anticipated, a suction pump can be installed on the flush water discharge pipe.



Consult a BSFc representative for further information and assistance.

Low pressure conditions

When low operating pressure condition is anticipated, a suction pump can be installed on the flush water discharge pipe. BSFc Automatic filters can function normally even at low operating pressure conditions of 1.5 Bar (21 PSI).



Consult a BSFc representative for further information and assistance.

BSFc Specifications

Minimum operating pressure:	21 psi (1.5) bar
Maximum operating pressure:	150 psi (10 bar)*
Electric power:	3-phase 380V-440VAC (50Hz)
Temperature range:	0ºC – 50ºC**
Exhaust valve:	Pneumatically (actuated) butterfly valve

* Consult your BSFc representative for higher pressure capability

** Consult your BSFc representative for higher temperature capability

BSFc's Automatic Electric Filter is made of the Following Materials:

Filter Housing:	Carbon steel with SMO fitting or St. St
Housing Coating:	200 micron protective coating extra durable polyester applied electrostatically and oven-cured on a zinc-phosphate layer, inside and outside, for maxima anti corrosion resistance
Screen:	Stainless steel 316L or Duplex materials
Seals:	Synthetic rubber
Internal parts:	St. St & PVC, Teflon, Erlite

BSFc Advantages:

- High screening efficiency.
- Fully automatic self-cleaning system efficiently handles heavy dirt load in raw water.
- Low operating pressures meet parameters of existing ballast water pumps.
- Uninterrupted filtered water supply during flushing.
- Long service life due to anti-corrosion protection coating and stainless steel screen.
- Low maintenance cost.
- Low cost per cubic meter of filtered water.
- Small "footprint".

BSFc reserves the right to change any of the information presented in this document without prior notice.
The data presented in this document is for general information only and can not be used for quotation purposes.
Please contact BSFc for specific quotes.

(version 2007)

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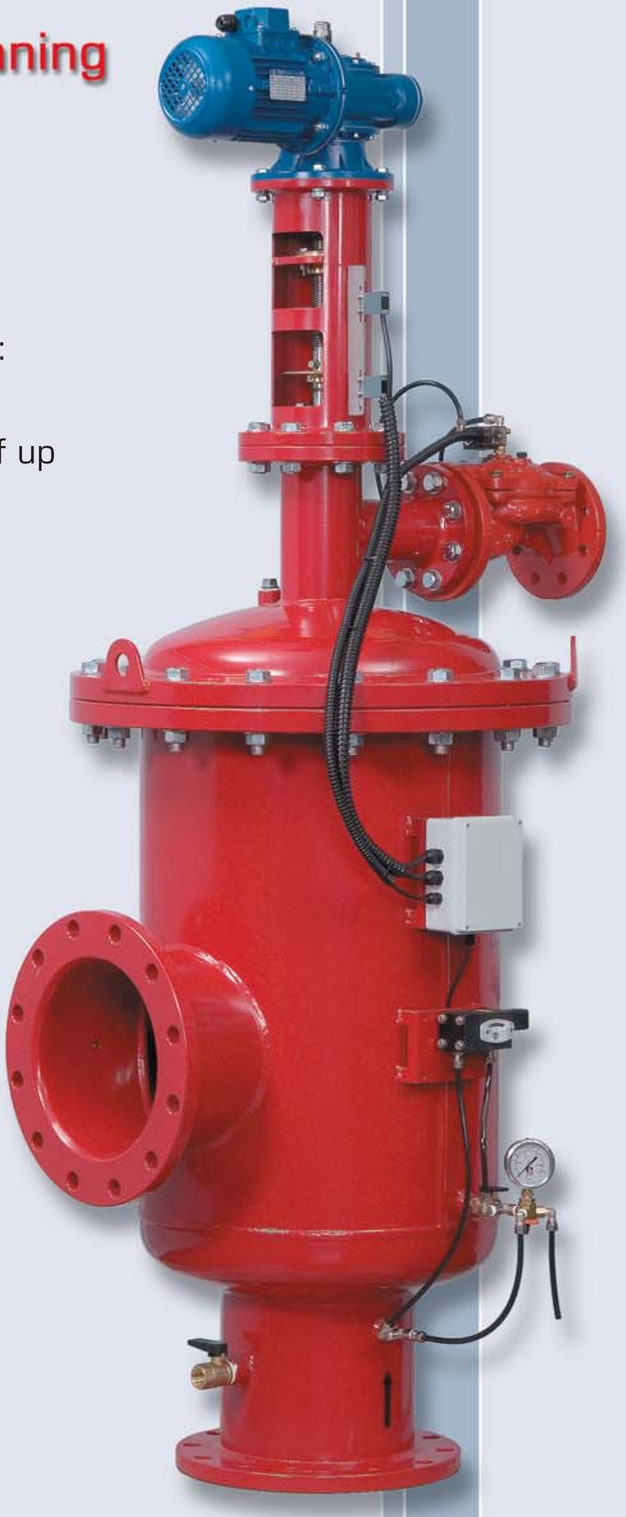
BallastSafe™
Filtration Company

"EBS" FILTER SERIES

amiad®

The largest automatic self-cleaning filter for fine filtration.

- For flow rates up to 4,800 m^3/h
- Fine filtration degrees: 800 - 10 micron
- Large filtration area of up to 40,000 cm^2



AMIAD FILTRATION SYSTEMS LTD.

HOW THE "EBS" FILTERS WORK

The EBS is an automatic filter, with a self-cleaning mechanism driven by an electric motor. The EBS is designed to work with various types of screens in filtration degrees from 800 to 10 micron, and is available in 8" to 24" inlet/outlet diameter.

Filtering process:

Raw water flows into the filter through the cylindrical filter element from the inside-out, causing particles to accumulate on the inside screen surface which causes the development of a ”filter cake”. The accumulation of the filter cake causes pressure differential to develop between the filter inlet and outlet.

A pressure differential switch senses the pressure differential across the screen and when it reaches a pre-set value, the cleaning mechanism is operated.

Cleaning process:

The EBS begins the self-cleaning process when the pressure differential across the screen reaches a pre-set value or an (adjustable) amount of time has passed. Cleaning of the filter's fine screen is carried out by the suction scanner which is a motor driven assembly that rotates while also moving linearly. It consists of a central tube with tubular nozzles equally spaced along the length of the central tube. An exhaust flush valve connects the internal cavity of the suction scanner to atmospheric pressure outside the filter body. By opening the exhaust valve, the differential pressure between the water inside the filter and the atmosphere outside the filter creates high suction forces at the openings of each of the suction scanner nozzles.

This suction force causes water to flow backwards through a small area of screen in front of each nozzle, pulling the filter cake off the screen and sucking it into the suction scanner and out through the exhaust valve to waste.

The driving mechanism rotates the suction scanner in a slow, controlled motion. The cleaning cycle is completed in approx. 30 seconds. During this time the nozzles cover 100% of the screen removing the filter cake from the entire screen surface. During the self-cleaning cycle, filtered water continues to flow downstream of the filter.

Control system:

The EBS filter is equipped with a pressure differential switch that transmits an electric signal to the electronic control board, which initiates the flush cycle.

A solenoid operates the exhaust valve by means of a hydraulic command or compressed air.

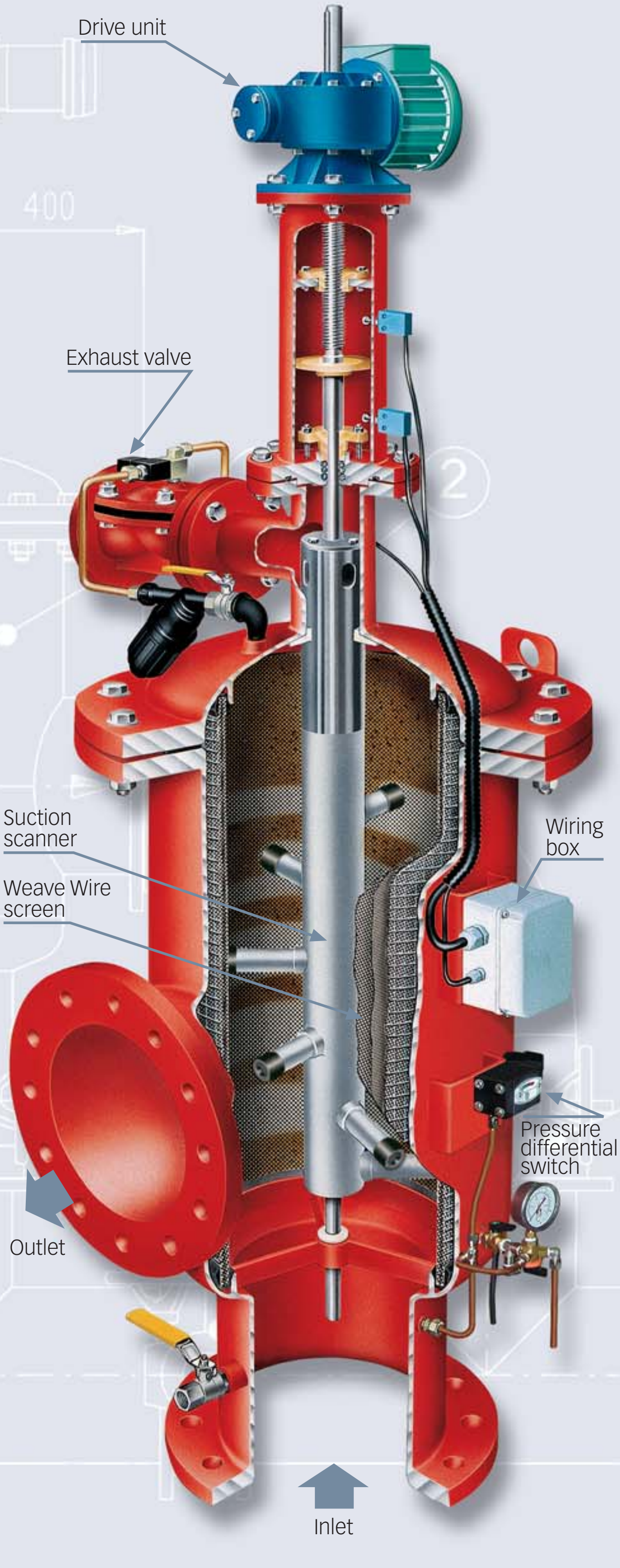
The filter operation and cleaning cycle are controlled and monitored by a Programmable Logic Control (PLC).

The PLC allows maximum flexibility in control options and has many features that can be incorporated per the customer's needs.

The MegaEBS:

The MegaEBS filter consists of four EBS screen elements and cleaning mechanisms within one housing. An integral control panel allows for sequential operation of the cleaning mechanisms, one-by-one, in pairs, or all four units simultaneously.

The Mega EBS is an excellent solution for applications with space limitations or when a limited number of filter units are required.



TECHNICAL SPECIFICATIONS

General

Filter type	EBS-10,000	EBS-15,000	MegaEBS	
Maximum flow rate [m^3/h]	1,200	1,800	4,800	Consult manufacturer for optimum flow depending on filtration degree & water quality.
Min. working pressure [bar]	2	2	2	Pressure requirements depend on multiple factors. Please consult manufacturer.
Max. working pressure [bar]	10	10	10	16 bar upon request.
Filter area [cm^2]	10,000	15,000	40,000	
Inlet/Outlet diameter [mm] [inch]	200 - 400 8″ - 16″	400 - 500 16″ - 20″	400 - 600 16″ - 24″	Flange standards upon request.
Max. working temp. [°C]	60	60	60	95°C upon request.
Weight (Av.) empty [kg]	490 / 350	684*	2,250*	In-line / On-line
Volume (Av.) [lit]	255 / 200	500*	2,800*	In-line / On-line

*Referring to In-Line models only (On-Line specs. on request).

Flushing data

Exhaust valve [mm]; [inch]	80; 3″	80; 3″	4 x 80; 3″	
Wasted water per cycle [lit]	420	500	1,680	at 2 bar
Min. flow for flushing [m^3/h]	50	50	200-50	at 2 bar
Flushing cycle time [sec.]	30	36	30-120	

Control and electricity

Electric motor [HP]	1/2	1/2	4 x 1/2	20/24 Gear output RPM
Control voltage [V]	24 AC			
Rated operation voltage	3 phase, 220-480V, 50/60Hz			
Current consumption [Amp.]	1.5	1.5	5.0	

Construction materials*

Filter housing and lid	Epoxy-coated carbon steel 37-2
Screens	Four-layer Weave Wire stainless steel 316L
Cleaning mechanism	Stainless steel 316L, Acetal
Exhaust valve	Epoxy-coated cast iron, Natural rubber
Seals	Synthetic rubber, Teflon
Control	Aluminum, Brass, Stainless steel, Nylon, PVC

*Amiad offers a variety of construction materials. Consult manufacturer for specifications.

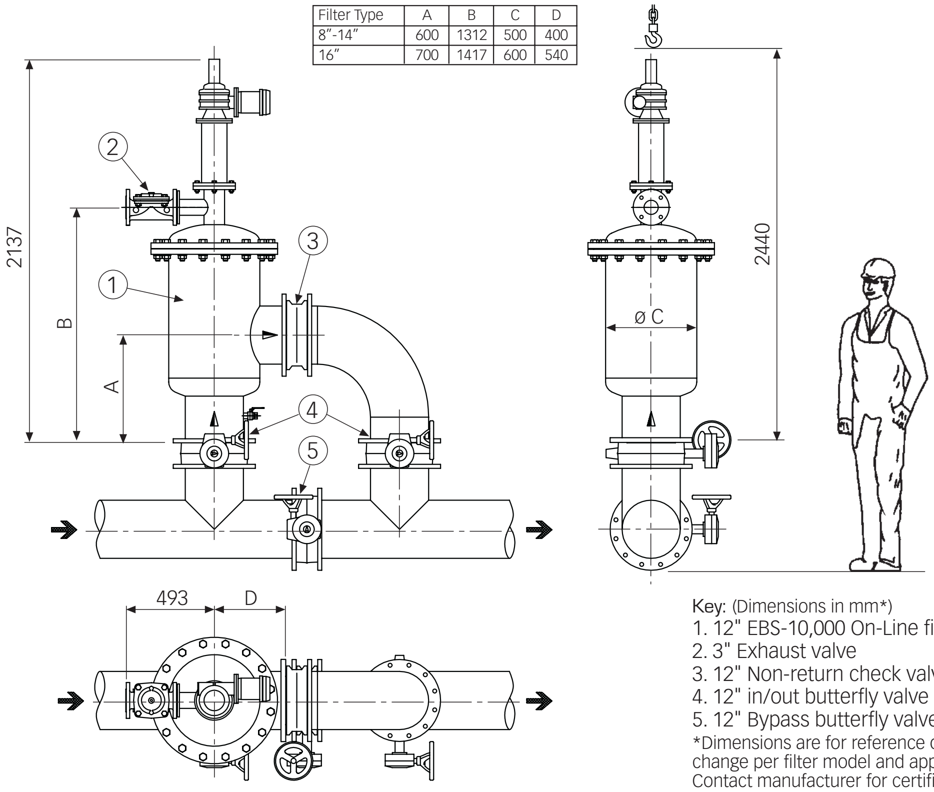
Standard filtration degrees

	Weave Wire stainless steel screen									
micron	800	500	300	200	130	100	80	50	25	10
mm	0.8	0.5	0.3	0.2	0.13	0.1	0.08	0.05	0.02	0.01
mesh	20	30	50	75	120	155	200	300	450	600

SUGGESTED INSTALLATIONS

EBS-10,000 On-Line

Filter Type	A	B	C	D
8"-14"	600	1312	500	400
16"	700	1417	600	540

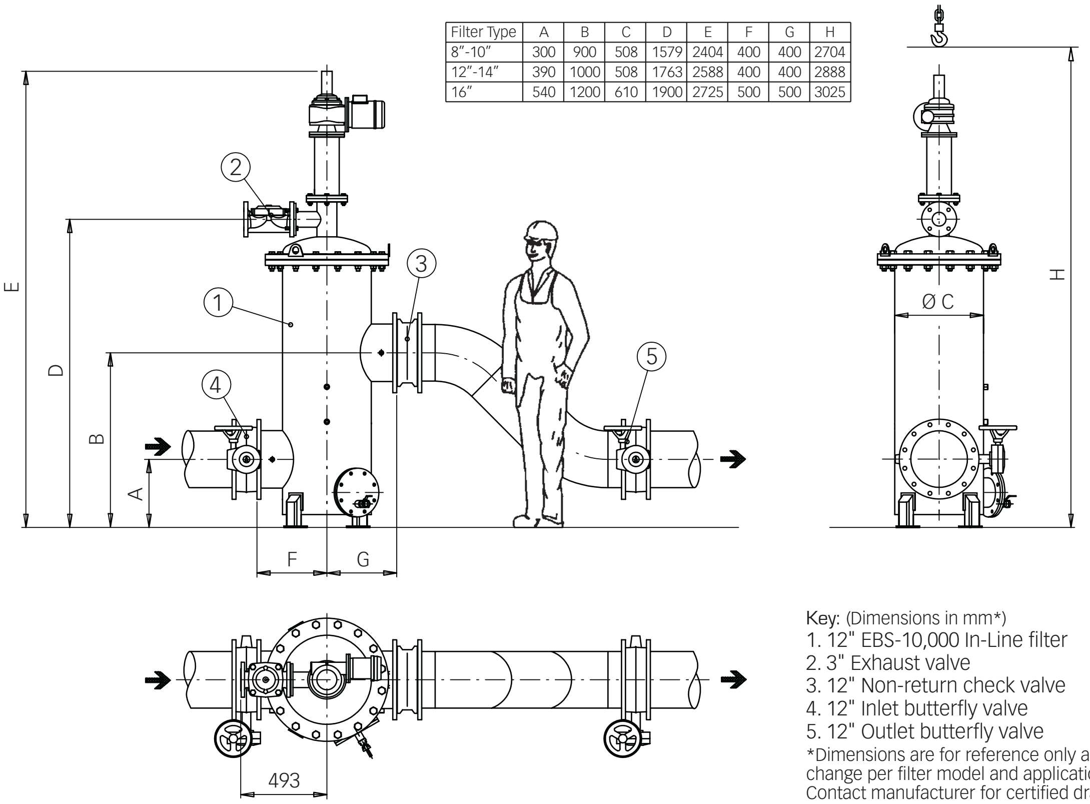


Key: (Dimensions in mm*)
1. 12" EBS-10,000 On-Line filter
2. 3" Exhaust valve
3. 12" Non-return check valve
4. 12" in/out butterfly valve
5. 12" Bypass butterfly valve

*Dimensions are for reference only and may change per filter model and application. Contact manufacturer for certified drawings.

EBS-10,000 In-Line

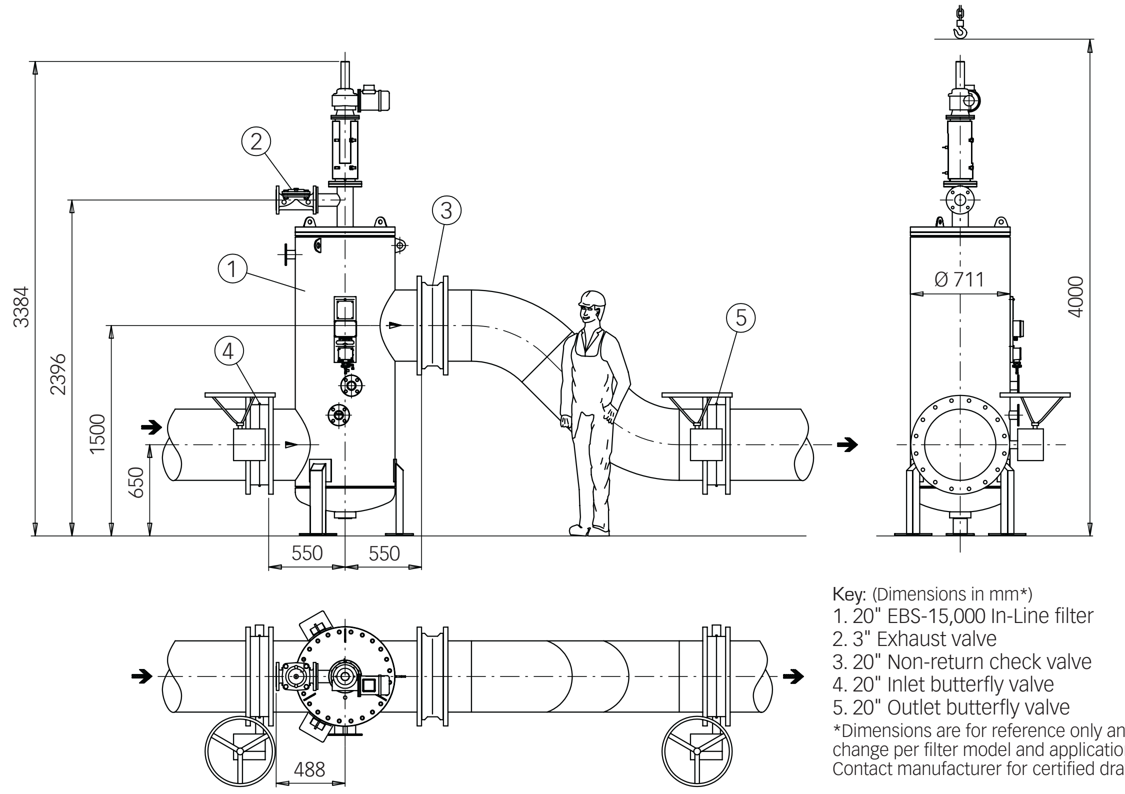
Filter Type	A	B	C	D	E	F	G	H
8"-10"	300	900	508	1579	2404	400	400	2704
12"-14"	390	1000	508	1763	2588	400	400	2888
16"	540	1200	610	1900	2725	500	500	3025



Key: (Dimensions in mm*)
1. 12" EBS-10,000 In-Line filter
2. 3" Exhaust valve
3. 12" Non-return check valve
4. 12" Inlet butterfly valve
5. 12" Outlet butterfly valve

*Dimensions are for reference only and may change per filter model and application. Contact manufacturer for certified drawings.

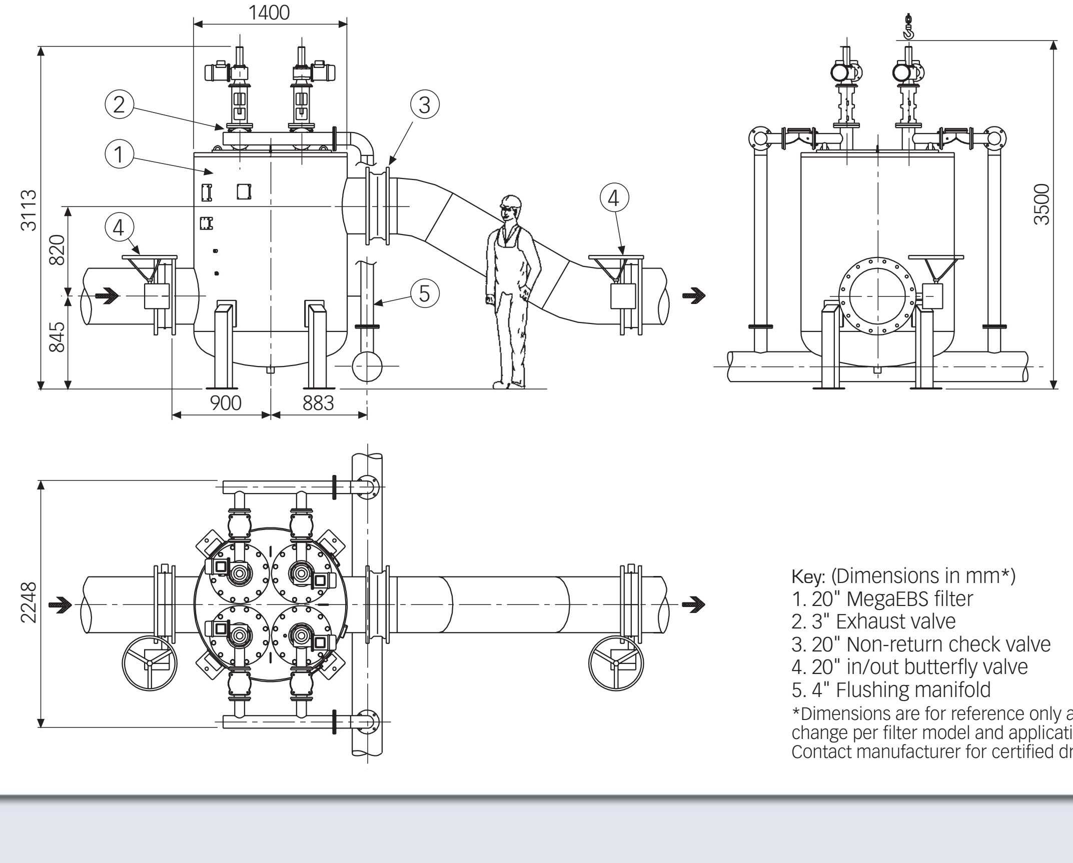
EBS-15,000



Key: (Dimensions in mm*)
1. 20" EBS-15,000 In-Line filter
2. 3" Exhaust valve
3. 20" Non-return check valve
4. 20" Inlet butterfly valve
5. 20" Outlet butterfly valve

*Dimensions are for reference only and may change per filter model and application. Contact manufacturer for certified drawings.

MegaEBS



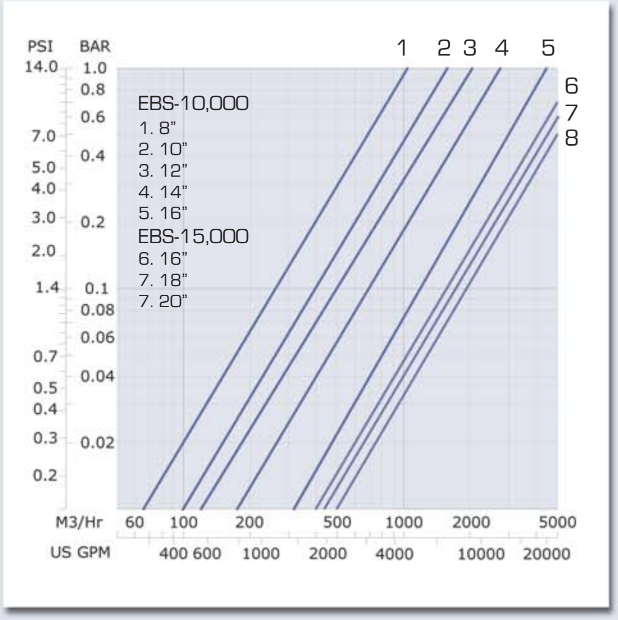
Key: (Dimensions in mm*)
1. 20" MegaEBS filter
2. 3" Exhaust valve
3. 20" Non-return check valve
4. 20" in/out butterfly valve
5. 4" Flushing manifold

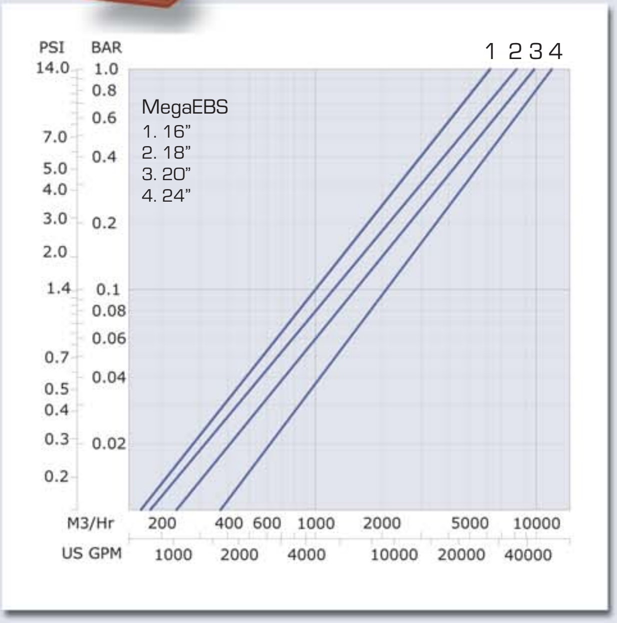
*Dimensions are for reference only and may change per filter model and application. Contact manufacturer for certified drawings.

PRESSURE LOSS GRAPHS

EBS

MegaEBS





SELECTED WORLDWIDE APPLICATIONS

Prefiltration to MF. 3,000 m3/h, 300µm. Clarified river water.
Olathe, KS. USA

Cooling tower at a steel mill. 16,000m3/h, 200µm. Southern China

Seawater application: Injection water filtration 220m3/h, 200µm and 25µm. On board "FPSO"

Drip irrigation for Almond Groves, 3,950m3/h, 130µm, river water.
Lachlan Farms, Australia

Side stream filtration of cooling tower water. 360m3/h, 25µm.
Huntley Power Station, New Zealand

Chinese army 14th division irrigation project. 14,000m3/h, 130µm.
Xinjiang, China

Frost protection system, dam water 7,200m3/h, 500µm.
ARA Project, New Zealand

Chinese army irrigation project. 16,000m3/h, 130µm. Xinjiang, China

Aquaculture - Zebra mussel control.
2,000m^3/h, 25µm. Vermont, USA

Cooling water in chemical plant.
460m^3/h, 130µm. Hamburg, Germany

Reservoir water for irrigation.
1,000m^3/h, 100µm. Kfar Hasidim, Israel

Industrial wastewater. 800m^3/h, 50µm. Electronic industry, Korea

Injection water. 2,000m^3/h, 50µm. North Sea Platform

River water for hot spa. 170m^3/h, 25µm. Japan

Pre-filtration to RO membranes. 1,700m^3/h, 25µm.
Desalination plant, Israel

SELECTED WORLDWIDE APPLICATIONS

Pre-filtration to DWTP. 375m^3/h, 50 µm. Dan river, Israel

Injection water on board FPSO. 220m^3/h, 25 µm. West Africa

Drip irrigation. 9,000 m^3/h, 130 µm. China

Drip irrigation of strawberries. 14,000m^3/h, 130 µm. Spain

Golf course irrigation. 700m^3/h, 200 µm. Tampa, USA

Irrigation water supply. 1,800m^3/h, 50 µm. Narbonne, France

Drip irrigation. 8,000m^3/h, 130 µm. Helche Creviente, Spain

Recreation and irrigation water supply. 3,400 m^3/h, 80 µm. Spanish Fork, USA amiad®

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